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ELEMENTS OF PHYSICS.

VOL. III.

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ELEMENTS

OF

PHYSICS.

BY

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INCIPAL OF THE ROYAL MILITARY COLLEGE AT DRESDEN,
ETC.

TRANSLATED FROM THE GERMAN,
WITH NOTES,

BY E. WEST.

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PART III.

IMPONDERABLE BODIES.

II.—ELECTRICITY, ELECTRO-MAGNETISM, AND MAGNETO-ELECTRICITY.

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ELEMENTS

OF THE

PHYSICS OF IMPONDERABLE BODIES.

PART II.

ELECTRICITY, ELECTRO-MAGNETISM, AND MAGNETO-ELECTRICITY.

SECTION IV.

ELECTRICITY.

I. ELECTRICAL PHENOMENA IN GENERAL.

§ 464.

Electricity is the etherial power which affects all our senses, and which produces the most varied results in its influence on all bodies whatever; it is diffused thoughout the globe, and resides in all terrestrial substances. As yet, it has not been ascertained whether its presence is confined to our planet, or whether it exists thoughout the universe.

Its presence is generally not perceptible in bodies, which are then said to be in a state of *electrical quiescence.* It is not, however, to be considered as certain, that electricity in this condition exerts absolutely no influence at all.

§ 465.

Electricity becomes sensible when this state of quiescence is disturbed, and the electricity is set *free.* Probably no change transpires in the material world which is not connected more or less intimately with a disturbance of this condition of repose, and an excitement of the electric power to a state of activity. The principal causes of electrical excitement with which we are at present acquainted, are the *friction* and *contact* of heterogeneous substances, *change of temperature*, the *vital process*, the *functions of the atmosphere*, the *pressure* and *rupture* of bodies, and *magnetism*. Philosophers are not unanimous as to whether *chemical action* and a *change in the aggregate form of matter* are capable of exciting electricity. The ordinary means of excitation employed are *friction*, *contact*, *heat*, and *magnetism*. According to the source from which it is derived, it is called *friction electricity*, *electricity by contact*, *thermo-electricity*, *and magneto-electricity*.

Faraday has demonstrated, that the electricity liberated by these varions modes is essentially the same; that the source whence it is derived affects its operations mainly in this respect, that one method will give us a small quantity of electricity of great intensity, whilst another will yield a larger amount of electricity, but of less intensity.

§ 466.

Bodies in a state of electrical activity are said to be *electrified*. The different phenomena which they display may be ranged under the following heads:

1.) *Mechanical phenomena*, which are observable in the motions, or even in the disruption of other bodies.

2.) *Luminous phenomena*, which are attended with a report more or less loud.

3.) *Thermal phenomena*, such as the incandescence, fusion, and combustion of bodies.

4.) *Chemical* effects, consisting of the chemical combination and resolution of bodies.

5.) *Physiological phenomena*, such as the production of a peculiar phosphoric odour, a sensation as if fine spider's webs were drawn across the face, an affection of the nerves of sight and taste; and lastly, a convulsive action of the whole nervous system, sometimes slight, at others more intense, and occasionally even mortal.

6.) *Magnetic phenomena*, affecting magnetic bodies, and imparting magnetic properties to non-magnetic substances.

The various exhibitions of this electrical power do not all occur simultaneously, or with equal degrees of intensity: in many cases they are so feebly developed that instruments are required to collect and render visible the effects produced. For this reason, it was formerly thought that only certain substances possessed electrical properties; with many of the phenomena of electricity we have become acquainted only within a comparatively short period.

§ 467.

The electrical state of any body, whatever may be the cause hich has induced that state, is estimated by the *quantity* and the *tensity* of the electricity which has been called forth into action. he electricity liberated may be measured, and its quantity may e expressed by means of any electrical effect that is assumed as e unit of measurement. Its density depends on its quantity, nd on the extent of the surface over which it is spread. If the uantities of electricity be equal, their densities will be inversely s their surfaces; *i.e.* if one surface be *n* times larger than nother, then the density of the same quantity of electricity ill be $\frac{1}{n}$th of that on the lesser surface.

§ 468.

The electrical state of a body may be merely *temporary*, *i.e.* n electrified body may, after the lapse of a longer or shorter eriod, lose its electricity, and resume its condition of electrical uiescence, when it will be said to have *discharged* itself. The me required for this purpose depends on the nature of the odies in contact with the surface of the electrified body, and their adiness for acquiring its free electricity. All substances pos- ss the property of withdrawing the free electricity from any ody with which they may be in contact, and appropriating it to emselves; when this is accomplished, they are said to be *electri- ed by conduction*. According to the time consumed in this pro- ess bodies are divided into *conductors*, *non-conductors*, and *bad nductors*. The loss of electricity sustained by any electrical ody may thus be measured: the means by which this is effected e shall explain presently.

Conductors are such bodies as become electrical instantaneously rough their whole extent, when the electricity is imparted to hem at any point of their surface; they also part as quickly ith the electricity they have acquired, if one end be connected y means of a second conductor with the earth. Their charac- eristic property consequently is, that *electricity may be readily xcited in them, and that when excited it is freely propagated.*

The *non-conductors* are substances which possess properties the ery reverse of those just described; *i.e.* they carry off free elec- ricity but slowly when touched by an electrified body, or if their ondition of electrical indifference is disturbed at any one point, hey become electrical at that point only; and if their whole urface be excited, and they are then touched by some conductor connected with the ground, they part with their free electricity only at the point of contact. Their characteristic is, that *they retain free electricity for a length of time, and that they check its motion.*

Hence good conductors can be electrified only when the free electricity they contain has no opportunity of escaping to the earth. To effect this we cut off their connection with it by supporting them on some non-conducting substance: when thus situated they are said to be insulated.

It was formerly thought that none but the non-conductors could be electrically excited, and that no other bodies possessed electricity; hence the name of *electrics* given to the former, and *non-electrics* to the latter class of substances.

Between these two extremes there is a large class of *indifferent conductors*, the time required by which for the transmission of electricity is so considerable as to admit of its being easily measured. A strongly defined line cannot be drawn between these three classes of bodies; neither does there exist any such thing as a perfect conductor, or a perfect non-conductor; but the conductors, arranged in the order of their conducting powers, descend gradually to non-conductors.

Experiment and observation have shown that free electricity attaches itself variously to these bodies; that in the conductors it is accumulated only at the surface; but in substances of low conducting power, when subjected to powerful electrical influences, it penetrates to the interior, and is firmly retained.

§ 469.

Our earth is the universal conductor to which all the free electricity from other bodies tends to return. The principal conductors are those metals which have a regular structure; then well burnt charcoal and graphite (black-lead); next the earths; then most of the salts and many liquids, both in a fluid and vaporous form. Among the liquids, the acids are distinguished for their conducting powers; next come the aqueous solutions of the acids and salts; and last of all water itself. All other solid bodies become conductors when moistened or damp; hence all animals and vegetables are conductors. Lastly, flame, smoke, and vacant space are conductors.

On observing the list just given of the best conductors of electricity, it will be perceived that many of them, especially among the solids, are also good conductors of heat.

§ 470.

Among the *non-conductors* are to be reckoned all kinds of glass, the precious stones, particularly the diamond, the metalloids, especially sulphur, all the metallic oxides, and the alkalies and earths, when perfectly dry; the combustible minerals, with scarcely an exception; to this class, too, belong all kinds of hair, indian-rubber, wax, dry vegetable products, as sugar, gum, dry wood, cotton, &c.; the fatty oils, æther; all animal coverings, as hair, skin, feathers, the webs of spiders and caterpillars, silk, raw and spun; ice, in proportion to its coolness; all dry gasses, in proportion to their density; and lastly, perfectly gaseous steam.

Of the different non-conducting substances enumerated above, shell-lac is the one which insulates most completely; but glass is the body most generally used. The atmosphere is the most widely extended, and the most important non-conductor. Had the air been a conductor, the phenomena of electricity would not have been visible to us. It is worth noting, that its conducting power increases in proportion to its rarity and the quantity of aqueous vapour it contains.

The principal substances of *mean conducting power* are paper, parchment, wood, horn, bones, ivory, marble, alabaster, and several other stones, when situated in the open air, and in their ordinary state of dryness.

§ 471.

The *conducting power* of bodies, or the readiness with which, in a given time, they transmit through their mass a certain quantity of free electricity, is an important element in the results brought about by this agent. It varies not only with the substance of a body, but also according to its dimensions and temperature. It may be remarked generally, that silver and copper, among the metals, have the highest conducting power, whilst lead and quicksilver have the lowest; that among liquids the highest rank is filled by nitric and sulphuric acids, and the lowest by water and alcohol; further, that the conducting power of all bodies is weakened by increasing their length; that its intensity is increased by enlarging their transverse dimensions; lastly, the conducting power of metals is weakened by raising their temperature, but that it is increased by heating all other bodies, and especially liquids; nay, even some substances which are non-conductors in the solid form, acquire a very considerable conducting power when fused or melted.

> Thus Sir H. Davy found that glass raised to a red-heat, melted sealing-wax, pitch, amber, shell-lac, sulphur and wax became good conductors.

From the difference in the conducting powers of bodies arises the difference in the resistance offered to the conduction of electricity; or, as Riess terms it, the *electrical retarding force.* It diminishes the electrical influence in the same proportion as the by combination each with its antagonist. This tendency is the more forcible the greater the intensity of the free electricity. (§ 467.) The fundamental effect produced by this tendency is the attraction of all such bodies as, by parting with their own electricity, would contribute to restore the state of equilibrium. Hence electrified bodies attract all other non-electrified bodies, and endeavour to saturate themselves with their opposite electricity. If the attracted body does not possess the requisite quantity of the fluid to saturate the attracting body, then the overplus of the free electricity is imparted to it, so that both bodies display an equal tension, and the body just now attracted is repelled. For similar reasons, every electrified body attracts to itself all oppositely electrified bodies. If they both contain equal quantities of opposite electricities, they saturate each other on contact being established, and both acquire a state of electrical indifference. If the quantities of the antagonist fluids are unequal, the bodies continue electrified after contact, and they both contain the electricity of that body, which, before contact, contained the largest amount of electricity. All similarly electrified bodies will repel each other, because the particles of the like electrical fluids exert a repulsive force against each other.

From a consideration of these phenomena, the following law of electrical attraction or polarity has been deduced: — *Like electricities* (+ E and + E, and − E and − E) *repel each other; but unlike* (+ E and − E) *attract; and if the quantities of dissimilar electricities be exactly equal, they neutralise each other*; that is to say, *they bring about the state of electrical indifference* (0 E). This law of electrical polarity bears a striking resemblance to that of magnetic polarity. (See § 437.)

The state of electrical tension may also be recognised by certain physiological effects, viz. a peculiar phosphoric odour, and a sensation as if spiders' webs were being drawn across the face.

§ 475.

The principal effect of tension, viz. attraction, is exerted in a radiant direction from an electrified point or ball, and its intensity decreases with the distance. By means of an apparatus, the construction and use of which we shall describe hereafter, Coulomb found that the law of forces acting from a centre was confirmed in this case, and that the intensity of these polar forces decreased as the square of the distance increased, *i. e.* at double the distance the intensity would be one-fourth; at three times the distance, one-ninth; at *n* times the distance, $\frac{1}{n^2}$ of what it is at the unit of distance.

§ 476.

The state of tension becomes converted into one of motion, or an *electrical current* is generated, if an opportunity is presented to an electrified body of combining with its antagonist electricity. This condition is fulfilled by establishing an immediate contact between the former body and one oppositely electrified; or, by connecting the two by means of a conductor; or, by connecting one of them with the earth. Under any of the arrangements just named, the dissimilar fluids rush together and neutralize each other on the passage offered them by the conducting medium. If two courses are presented to the fluid by which it may make its exit, it will select that where it meets with the least resistance, and if the conductors be equally good it will select the shorter.

The time that a current of electricity will last, depends on the retarding power of the conductor, and on the quantity of the fluid to be discharged; if this be but small, and the cause which induced the state of tension be merely temporary, the duration of the current is not appreciable in a good conductor, and the current is said to be *momentary* or *instantaneous;* if, on the contrary, the cause by which the tension is brought about continue for some time in operation, the current will be maintained so long as free electricity is generated and the current is said to be *permanent*. The momentary current is generally excited by frictional electricity, and the permanent by electricity by contact, by thermo-electricity, and by magneto-electricity.

The effects produced by a current of electricity are various. A momentary current, from a high degree of electrical tension, generally displays itself in intense luminous phenomena; in the disruption, combustion, incandescence, and fusion of bodies; in the violent convulsions of the nerves. It also produces feeble chemical and magnetic influences. A permanent electrical current, on the contrary, is marked by its powerful chemical influence, by an intense and permanent excitation of heat, and lastly, by its magnetic properties. The permanent electrical current exerts a less intense luminous influence, and acts slightly on the nervous system.

The explanation given above is based on the theory of two fluids which are supposed to move towards each other. According to Franklin's hypothesis, it is only the positive electricity, or the excess of the fluid in the two bodies, which is in a state of motion. This excess he supposes to go over into the negative body, *i. e.* into the body which has less than the normal quantity of electricity.

§ 477.

The velocity with which a current of electricity travels is greater even than that of light itself. Wheatstone, in an experiment, which will be described hereafter, estimated it at 288,000 miles, being half as great again as that of light. This is the rate at which it travels in copper wire, whether its velocity is as great in other conducting bodies has not yet been ascertained.

§ 478.

Electrified bodies also effect a resolution of the neutral electricity in unelectrified bodies into its elements (+ E and — E), when the latter are brought into proximity to the former. The distance at which the body originally electrified exerts this influence is termed its *electrical atmosphere*. This electrical excitement varies as the exciting body is in a state of tension, or is emitting a current of electricity. In the former case, bodies brought within the sphere of its influence are themselves put into a state of tension; in the latter, they discharge their electricity in a stream. The unelectrified bodies thus put into a state of electrical activity recover their original quiescence as soon as they are removed beyond the atmosphere of the exciting body. The electricity thus excited is said to be *induced*, and the process is called electrifying by *induction*. The special phenomena exhibited by induced electricity will be noticed in the course of this section.

II. FRICTIONAL ELECTRICITY.

A. *Fundamental Effects and Phenomena of Frictional Electricity.*

§ 479.

When two dissimilar substances are rubbed together, they are both brought into a state of electrical tension, conductors becoming electrified throughout their entire surface if insulated, non-conductors becoming so only at the parts subjected to friction. If one of the bodies be a non-conductor and the other a conductor, and the latter be connected with the ground, the former will be rendered susceptible of a more powerful tension. The electrical *condition of* these bodies may be most readily recognized by heir attracting and repelling unelectrified bodies. A faint lumious appearance will also be visible, and the physiological pheomena described above (§ 474.) will be observable, but in a low egree. The following experiments will illustrate these phenoena.

First Expt. Rub a glass rod, or a stick of sealing-wax, with a woollen cloth, or with a piece of silk a few times, and you will observe: —

1.) Both the non-conductors which have been rubbed attract small pieces of paper, feathers, or similar light substances, and then repel them. The same may be seen by suspending a pith ball by a silk thread and presenting it to the electrified body.

2.) If the knuckle of your hand, or a small brass knob, be offered to the surface of the bodies you have rubbed, a snap will be heard, and if the room be darkened a small spark will be visible.

3.) If the glass rod be large enough a sensation will be felt as if spiders' webs were drawn across your face on bringing the rod before your eyes.

4.) Place the glass rod under your nose, and you will perceive a faint smell like phosphorus.

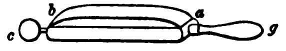
As the substances named in this experiment are non-conductors, these effects will be perceptible for some time, even though they may be touched in several parts of their surface. (§ 468.)

Second Expt. Hold a metal rod in your hand and rub it in like manner; none of these phenomena will be produced by it. The metal when grasped by the hand is not insulated, the electricity elicited is conveyed by the body of the operator to the ground. (§ 468.) The same remark holds good with regard to any other conductor; for which reason, these substances were long considered non-electrics.

But if a metal rod or plate be insulated, by fixing a glass handle on it, friction will render it electrical; if any point of its surface be touched, it will at once part with its free electricity, because of its conducting properties. (§ 468.)

Third Expt. To prove that both the bodies are electrified by rubbing them together, we must next offer some extremely light substance to the cloth or silk with which the rod of glass or sealing-wax has been rubbed; even then, perhaps, its electrical properties may not be evident. To verify the existence and to measure the intensity of these we must use some one of the delicate electroscopes which will be described in the succeeding paragraphs, or else the rubber must be so arranged that the electricity set free by the friction may accumulate itself on a conductor. Fig. 149. repre-

Fig. 149.



sents an apparatus contrived for this purpose. It consists of a piece of wood, in shape somewhat resembling a bat; on one side of which, *a b*, some strips of cloth are fastened. This is then covered with a piece of tinfoil of equal length and breadth, over which is placed a piece of soft calf's skin or linen, coated with some of the amalgam described in § 482, and then a piece of silk is strained over the whole. At one end of the rubber is placed a metal knob *c*, connected with the tinfoil, and intended to receive the electricity set free in the rubber; at the other end is a glass handle *g*, by which the instrument is held. If the cushion be rubbed with a glass rod, the knob *c* will immediately be electrified.

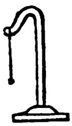
The attractive and repulsive properties of amber, *ἐλεκτρον*, when excited by friction, were discovered at a very remote period, and for a long while this was all that was known concerning the nature of electricity. It was not till the year 1600 that the same peculiarity was observed in other bodies, and for more than another century the science of electricity thus remained in a state of infancy. In the course of the 18th century it was gradually elevated by several men of science to an important rank in physics; but the most rapid advances have been made during the present century, and indeed during the last ten or twelve years of it. Since the discovery of electro-magnetism the most distinguished philosophers have laboured to carry out these recent discoveries, and to place on a firm and scientific basis a theory by which the varied phenomena of electricity may be satisfactorily accounted for; the completion of this object still remains to be accomplished.

§ 480.

Very often the electrical tension excited in a body is of so feeble a character, that its existence is not indicated by any of the effects yet described. In such cases we are compelled to have recourse to a class of instruments called *electroscopes*, or *electrometers.* The former merely show when a body is in a state of electrical tension, and what species of free electricity it possesses, whether positive or negative; the latter enables us to measure the intensity of the tension. They act in obedience to the universal law of electrical polarity (§ 474.), their most essential part being some good conductor, which moves very readily as it is attracted and repelled. They may be divided into the following classes according to the mode of their construction: — 1.) electroscopes in which only one moveable, light, and insulated conductor is first attracted and then repelled; 2.) electroscopes in which two such conductors repel each other after they have been impregnated with the electricity of the body under investigation; 3.) those in which only one of the conductors moves as it is attracted and repelled by the fixed one; 4.) those in which a moveable insulated conductor is placed between a positively and a negatively electrified body, so that when it has acquired the electricity of the body under examination, it will be attracted by that which is dissimilarly electrified. In all those instruments which are intended to serve as electrometers there must be a scale on which to measure the repulsion and attraction of the conducting body that acts as an index of the electrical tension, and by which we may be enabled to calculate the intensity.

The electroscopes of the first class in most common use are the following:— The *electrical pendulum* (*fig.* 150.) consists of a small pith ball, suspended by a silk thread. This is a very simple, but not a very sensitive apparatus. *Haüy's electrical needle* (*fig.* 151.) is very much like a common variation needle balanced on a point; at one end of the needle a small pith ball is fixed, that portion of it which carries the ball being of glass, whilst the other half, which serves as an equipoise, may be made of copper. This apparatus is much more sensitive than the other, and is well adapted to show the fundamental effect of attraction and repulsion.

Fig. 150.



The following instruments belong to the second class of electroscopes, and admit of being used as electrometers.

Fig. 151.

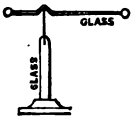
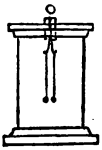


Fig. 152.



Cavallo's cork or pith-ball electrometer consists of two balls of cork or pith fastened to two very fine wires, which are attached to a conductor that conveys the electricity to them. (See *fig*. 152.)

Volta's straw electrometer is exactly like the preceding, only that fine straws are substituted for the wires employed in Cavallo's electrometer.

Bennett's gold-leaf electrometer is similarly constructed, but law of electrical polarity (§ 474.), that like electricities attract, and unlike repel, we may easily ascertain of which kind the electricity of any particular body is, by bringing it within the influence of some substance whose electricity is known. This we shall proceed to illustrate in the following experiments: —

First Expt. Electrify two pendulums (*fig.* 150.), or two needles (*fig.* 151.), by means of a glass rod, which you have excited by friction with a piece of silk or cord; they will both acquire the + electricity set free in the glass; it will accordingly repel them, and they will become repulsive to each other.

If we use a stick of sealing-wax instead of the glass rod, precisely similar phenomena will be observable, but in this case the electricity will be —.

Thus we have experimentally proved that similarly electrified bodies repel each other.

Second Expt. Impregnate one of these electroscopic bodies with the + electricity of the glass, and the other with the — electricity of the sealing-wax; the former will be attracted by the negative sealing-wax, and the latter by the positive glass rod, and the bodies themselves will be mutually attractive.

We have now verified the second part of the law of polar forces, that unlike electricities attract.

To test the character of the electricity which is liberated in bodies that are in a state of but slight electrical tension, we are obliged to have recourse to a more delicate electroscope than either of those referred to in the two preceding experiments. The most convenient is Becquérel's pile electrometer, (*fig.* 157.), which shows both the quantity and the kind of the electricity. In other electrometers we are obliged, first, to impart to the electrical bodies the electricity of the body under investigation, and then to test them by means of an excited glass rod or stick of sealing-wax.

Third Expt. Rub a glass tube on a piece of woollen cloth or silk, rolled up tight, and the glass, if tested by an electroscope, will be found to be + electrified, and the woollen cloth or silk to be —. These substances have therefore acquired opposite electricities. It will be found convenient to wrap the silk or flannel in folds over a piece of wood in the shape of a bat.

Fourth Expt. Rub a glass tube up and down the rubber just described, and you will find both the flannel and the silk — electrified; substitute a stick of sealing-wax for the glass, and the electricity will be +.

Rub a smooth glass rod with the hand, and it will become + electrified; but if its surface be rough, similar treatment will render it — electrical.

> These experiments prove that the same substance may, by friction, acquire both + and − electricity.
>
> *Fifth Expt.* Plates, about 3 inches in diameter, either of the substance to be examined, or of some other material on which it can be spread, will be found very convenient for determining the electricities liberated on rubbing two substances together; the plates must be insulated by means of glass handles. After they have been rubbed together, the plates are to be separated, and if offered to a delicate electrometer, it will be found that one of them is + and the other − electrified.

Several eminent men of science have endeavoured to discover a law, by which we might know beforehand what would be the electrical condition of any two bodies when rubbed together. The following rules seem generally to be observed with regard to non-conductors: —

1.) The *hardest* substances appear to be especially susceptible of *positive* electricity.

> The diamond, for example, which is the hardest known substance, is invariably + electrified by friction, against any of the other precious stones or against glass; sulphur is not so hard as amber; the former is always − electrified, and the latter +: other instances will readily suggest themselves to the student.

2.) Of two similar substances, that which by friction becomes the *hotter* is *negatively* electrified, and the *cooler* one *positively*.

> *Sixth Expt.* Rub two silk ribbons together, by drawing one cross-ways to the other; that which is drawn lengthwise will have a + electricity, and the other a −.
>
> Rub a piece of ground-glass on a polished glass, the former will be − and the latter + electrified.

It has been further ascertained, that of all known substances, a *cat's back* is the most positively electrical, and *sulphur* probably the most *negatively* so; that is to say, against whatever substance you may rub the former, it always acquires + electricity; and the latter as constantly − electricity. All other bodies may be so arranged between these two extremes, that each on being rubbed with one of the substances, in order below it, will acquire + electricity, and the body with which it is rubbed − electricity; and that the state of tension thus induced is more powerful, the wider the distance in the series between the two bodies. So many circumstances affect the electrical properties of bodies, that as yet no list has been made out that can be regarded as absolutely correct.

> Pfaff gives the following list of insulators, beginning with the most positive; if they are taken in pairs, the first will be positive, and the succeeding body negative: —

+ a cat's back, diamond, dog's skin, tourmaline, glass, wool, paper, white silk, black silk, sealing-wax, colophon, amber, sulphur —.

The following is Ritter's list for the electrical tension of both non-conductors and conductors: —

+ diamond, zinc, glass, copper, wool, silver, black silk, grey silk, grey manganeseous earth, sulphur —.

§ 482.

The non-conductors, especially glass and resinous bodies, are used for exciting the highest degree of electrical tension, by rubbing them against some suitable substance, which is generally of a soft elastic texture. Experiment has shown, that an amalgam of tin, zinc, and quicksilver (*a*), mixed with some unctuous matter, and spread on silk or leather, forms the best instrument for exciting glass; resinous bodies are most readily affected by rubbing with the skin of a cat.

a.) Pfister says that this amalgam is best prepared by mixing 2 parts of tin with 3 of zinc, and 4 of quicksilver. The zinc is to be melted first, then add the tin as soon as the mixture becomes fluid, stir it for some time and pour out into a wooden box, on the inside of which you have previously sprinkled some chalk: the mercury should be heated and poured into the box before you add the other two metals; the lid should then be put on, and the box is to be violently shaken till the amalgam becomes cool, when it may be finely pulverized in a mortar.

The conductors, and especially the metals copper and brass, are used for receiving by *conduction* the electricity set free in the non-conductors; to effect this, they must be connected with some non-conducting substance, most commonly with glass. The conductor instantly diffuses (§ 468.) the electricity imparted to it over its whole surface, which is put into a state of electrical tension; the manner, however, of its diffusion is materially modified by the form of the conductor itself. If it be a sphere, then the tension is equal at every point of its surface; if its dimensions be unequal, the tension will be most powerful in the direction of its length, the greatest force being at the extremity of the body. Cylinders will serve as an illustration of what is meant; but if the conductor terminate in a sharp edge or point, the electricity will so accumulate in these parts, that, unless it be extremely full indeed, it will overcome the insulating resistance of the air into which it will make its escape.

The influence which the form of the conductor exerts on the intensity of the electrical tension at its surface, may be thus accounted for. So long as an insulated conductor is in its natural state of electricity; *i. e.* so long as the two fluids are in a condition of equilibrium, it may be assumed that they are equally distributed throughout the body's mass. But when either + or — electricity is accumulated in a body, the single elements of the free electricity repel each other and recede until some resistance is offered to their further expansion. If now the conductor be perfectly homogeneous, no such cause of resistance exists, and the electricity necessarily accumulates at the surface; and if it be surrounded, as it usually is, by the atmosphere, then the latter will oppose the required resistance to the further expansion of the fluid, since the air when *dry* is a very imperfect conductor. Now, if the force be transmitted from the centre, its repulsion will obviously be equal in all directions. In conductors of a spherical form, the electricity will constantly be spread in a film of uniform density, over the surface of the conductor. Hence, also, the more the figure of the conductor differs from a sphere, the more unequally will the fluid be distributed about its surface. The accumulation of electricity will be greatest in those parts which are the most remote from the middle; because in them will be the greatest quantity of repulsive elements; its intensity will increase the more the end of the conductor approaches in form to a point, where the electricity will, of necessity, be the most dense. But the denser the electric fluid at any particular point of the surface of an insulated conductor, the more readily will it overcome the resistance of the air; hence the electricity passes off with such ease from points.

To insulate a conductor completely, so that it may retain the electricity with which it has been impregnated, its figure should be free from all points or edges; even when the best form has been given to a conductor, its tension gradually diminishes; *i. e.* it suffers a loss of its electricity, and after some time it resumes its original condition of quiescence. This loss is owing to the fact, that no absolute non-conductor exists (§ 468.): those bodies to which this name has been given, do but retard in various degrees the escape of the fluid. The atmosphere exerts the most powerful influence on a body's conducting properties, as it is in immediate contact with every part of its surface; the moister the atmosphere, the more rapidly does it convey away the electric fluid. According to Coulomb's investigations, the loss is equal in equal times, the condition of the air remaining the same, and the greater the electrical tension the greater the loss; when the tension is but feeble, bad conductors act nearly as well as non-conductors.

Coulomb made use of his electrical torsion balance to estimate the amount of this loss. According to one of these electricities combine, and the conductor recovers its state of neutrality.

> *Second Expt.* Proceed, as we have described above, with both the bodies, viz. with the insulated conductor (*a b*, *fig.* 158.) and the jar A; the return of the former to its state of indifference will be evident by both the pendulums falling down.

If the conductor, whilst in a state of induced electricity, be touched at any point whatever, it will lose the electricity of the same name with that of the inducing body; but the dissimilar electricity at the end nearer to the exciting body will be in a state of greater tension. This phenomenon has caused the first electricity which is carried off to be called *free*; whilst the other, which is retained by the opposite electricity of the inducing body, is said to be *latent*. Remove the conductor in this state beyond the action of the electrified body, and it will again appear electrical, the whole of its surface being electrified with the opposite electricity to that of the inducing body. The electricity held in a latent state in the conductor by the action of the other body, is again set free, and spreads itself over the whole surface of the conductor.

> *Third Expt.* Touch the conductor (*a b*, *fig.* 158.) with your finger, at any part of its surface, and the pendulum *b* will sink, whilst that at *a* diverges still more widely. Place the two bodies apart, and all the little pendulums attached to the body in which the electricity has been induced assume an equal divergence; and if the character of the electricity be tested by means of an excited glass rod, or stick of sealing-wax, it will be found to have an opposite polarity to that of the exciting body; as represented in the figure, the whole of the conductor would be negatively electrified.

From what has been now advanced, it is clear that important differences exist between induced electricity and electricity by conduction. For 1.) Induction occasions no transmission of the free electricity to the other body, and consequently no combination of the ± electricities, such as obtains when electricity is excited by conduction; but the free polar force in the electrical body exerts a tendency to combine with its opposite electricity in the body on which its inductive influence is exerted. 2.) The distance at which electricity acts in this manner greatly exceeds that at which it acts by conduction; for in the latter case it is necessary that absolute contact should be established, or, if the tension of the free electricities be very great, there may be an interval between the two bodies, if it be so small that the ± electricities can neutralize each other in the stratum of air which intervenes. 3.) Induction always produces the dissimilar, but conduction produces the similar, electricity to that of the electrifying body; *i. e.* all *bodies within* the sphere of a positively electrified body's influence re negatively electrified, such as are within the atmosphere of a egatively electrified body are positive.

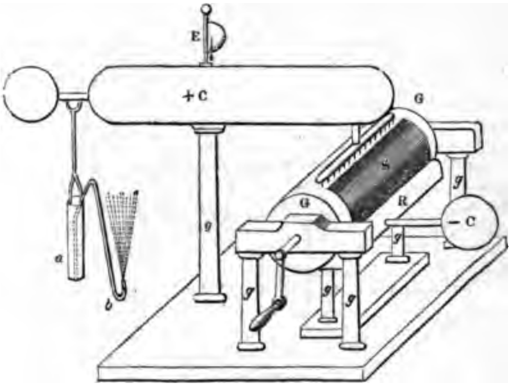
Thus, although an electrical body, acting by induction on nother, sustains no loss as to the quantity of electricity it contains, yet the intensity of its electrical tension is materially modified whilst it is in a state of polar activity. The intensity is lessened by just that amount of the free polar force which is engaged in attracting to itself its antagonist force; and hence the body is enabled to draw still further supplies of electricity from the other body from which it has already derived some by conduction. In other words, during the process of induction a body acquires an additional *capacity* for receiving fresh electricity, the density of which increases in proportion to the quantity added. On the mutual relation which thus obtains in bodies electrified by induction, depends the construction of those important instruments which serve to condense electricity and to increase its power. A full description of these will be found in §§ 486—490.

The inductive influence of electricity obeys the same laws in onductors not insulated as in non-conductors, but in the former ts effects are not apparent, as they are neutralized by the connection of the body with the ground, whereas, in non-conductors, he influence is extended to but a small distance from the electrifying body; the resistance to conduction is, of course, the obstacle o its more rapid progress. Beyond these limits an alternate tate of tension is found, several *zones* of induced electricity following each other, of which, each succeeding one lies within the lectrical atmosphere of the preceding, but as the distance from he original point of excitation increases, the zones become eaker and weaker until they entirely vanish, agreeably to the aw which regulates the decrease of electrical influence.

The process of induction may be advantageously applied to the use of the electroscope and electrometer, if the instruments, like Becquérel's and Oersted's, are sufficiently delicate for the purpose. When brought near the electrified body they are excited, and the electroscopic substances diverge agreeably to the law of induction, with the electricity of the exciting body. Whilst the instrument is in this state lay your finger on the conductor, the free electricity will be carried off, and the electroscopic substances will no longer appear to be affected; but if the finger be withdrawn, and the body, whose electricity you are testing, be also removed, the electrometer will again show itself to be in a state of excitement, but with the opposite electricity to that of the body under investigation. This may be proved in the manner which has been already explained several times. The electrometers named above, and also the torsion balance, will be rendered additionally sensitive, by imparting to them a placed horizontally, and turned about on its axis by means of a handle: immediately under it is the rubber, which covers from ⅛ to ¼ of the surface of the cylinder, against which it is pressed by a steel spring. That the electricity set free in the cylinder during friction may not be dispersed in the air, a piece of silk is fastened to the upper side of the cushion, extending as far as the conductor, to which it conveys the electricity it carries off from the glass. To collect the electricity set free in the cushion, the latter must be insulated upon glass legs.

The conductor, which is intended for the reception of the electricity from the glass cylinder, is called the *positive conductor*. Its form, as has been stated before, is commonly cylindrical, and its position is generally horizontal, so as to stand at right angles with the axis of the cylinder. That it may receive the electricity from the whole surface of the glass which is subjected to friction, one end of the conductor stands exactly over the middle of the cylinder, having a smaller metal cylinder connected with it, the latter going lengthwise along the cylinder, and being furnished with teeth or points that nearly touch the surface of the glass. The conductor of the cushion, when the machine is fitted up with one, is called the *negative conductor*; it generally consists of a large hollow metal ball, immediately connected by a wire with the cushion or rubber. *Fig.* 159. represents

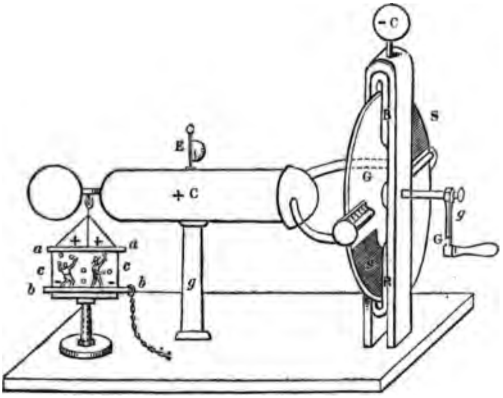
Fig. 159.



an electrical machine, with all the parts we have just described; G G is the glass cylinder, R the rubber or cushion, with the piece of silk S, + C is the positive, and – C the negative conductor, *g g g g* are the glass legs on which it is insulated.

In the *plate-machine*, as its name indicates, a plate of glass is substituted for the cylinder; an axis passes through its centre, the ends of the axis rest in two sockets in two upright pillars, between which the plate is made to revolve by means of a handle, which fastens on to the end of the axis. The cushions, against which both sides of the plate rub, are so fixed between the vertical pillars, that they are pressed opposite to each other against it. These cushions are also provided with silk flaps, which fit close to the surface of the glass. The handle by which the circular plate is turned stands on one side, and on the other is the conductor, consisting of two arms having at their ends small toothed cylinders, which come close to the surface of the glass. If these machines are fitted up with a negative conductor, the simplest plan will be to place it above the two upright pillars which support the machine. This conductor consists of a hollow metal ball, which must be connected with the cushions. *Fig.* 160. represents a plate electrical machine; G G is the plate, R R the rubbers with the silk flaps S S, + C is the positive, and – C the negative conductor.

Fig. 160.



Cylinder machines with equal area of surface, exposed to

§ 485.

All the effects of electrical tension hitherto described, may be produced much more plainly, and in a higher degree, by means of an electrical machine, than in the fundamental experiments given in § 479.

Insulate both the conductors of a machine, and after the cylinder or plate has been turned round a few times, they will both be in a state of high electrical tension, as a quadrant electrometer E, *figs.* 159. and 160., placed on the positive conductor would immediately show; the conductor in connexion with the glass is positively electrified, that which is connected with the cushion is negatively electrified, as may be easily seen by applying the tests already described. In this state of tension, both the conductors will attract unelectrified bodies held at certain distances from them, and then repel them. So their inductive influence may be observed on electroscopes at a considerable distance.

> A thread 6 feet long was drawn 6 inches out of the perpendicular by Van Marum's great plate machine at a distance of 38 feet from the conductor, and the balls of one of Cavallo's electroscopes diverged ½ an inch asunder when 40 feet from it.

During the revolution of the machine, a luminous appearance is very perceptible, accompanied by a crackling noise; and small sparks are visible in those parts of the cylinder or plate which are not covered with the silk flap.

If the face be placed near the excited bodies, a sensation is distinctly felt, as if spider's webs were being drawn across it; and very shortly after an electrical machine has been in use, the phosphoric odour is strongly perceived.

If both the conductors be insulated whilst an electric machine is worked, they will acquire only so much electricity equals the quantity of quiescent electricity which is decomp by the friction of the glass and the rubber. In proportion as th free electricity transmitted to the conductors is dispersed in air, the intensity of the electrical tension diminishes. To ob from the machine a permanent supply of electricity in a hi state of tension, it is necessary therefore, that one of the bod which are rubbed together, should be kept in a state of electri quiescence, which is accomplished by connecting it with earth; if we desire to obtain positive electricity, we shall con the cushion with the ground, if negative, the positive conduc Generally speaking, for experimental purposes we use positi *electricity*, which is obtained of greatest intensity by connecti ushion by means of some good conductor, such as a copper or chain, with a large mass of metal, such as a water, gas, or air pipe.

he electricity accumulated in the conductors may be trans- ed to other bodies in two different ways, according as the r are immediately connected with the conductor, or are held me distance from it. In the first case, the free electricity ch is transmitted to the conductor passes on without any eptible mark to the body connected with it, and the body is in the condition described in § 482.: that is to say, if a non- ductor, it is electrified only at the points of contact; if a con- tor in an insulated position, its whole surface is electrified; if nductor not insulated, the electricity transmitted to it in- tly escapes into the ground; so that neither it nor the con- tor manifests the least presence of free electricity. The ectness of the above remarks may be easily tested by the owing experiments:

First Expt. Touch an electrified conductor with some point of a non-conducting body which you have previously marked, test the non-conductor by means of an electroscope, and you will find it electrified only at the point which had been in contact with the conductor.

Second Expt. If a person stand on an *insulating stool, i. e.* on a wooden stool with glass legs, and place one hand on the conductor of an electrical machine which is set in action, a person so placed being an insulated conductor of electricity, will be electrified in precisely the same manner as the prime conductor of the machine.

Third Expt. Connect the rubber with the ground, and either suspend a chain or lay your hand on the prime conductor while the machine is being turned round, and the prime conductor will show no mark of free electricity, which will however be developed immediately on removing the hand or the chain.

But if a body be brought gradually towards the conductor ile in a state of electrical tension, the conduction of the elec- city will take place, even before contact happens, with a *spark* ended with a crackling noise or a report. The *length* of the rk is the greatest distance at which an object can be held m the prime conductor in order to elicit a spark. This species onduction may be explained by referring it to the inductive luence of the conductor on the body which is moved towards ; those parts of each which are next to the other, as they are ught nearer and nearer together, acquire so violent a degree electrical tension, that at last the resistance offered by the in- vening stratum of air is overcome, and a spark is elicited by combination of the + and − electricities; the length of the

the conductor with the wire by means of a chain, and then setting the machine in motion, or else by holding the knob at the top of its wire near the conductor, while the machine is at work, and a succession of sparks from the conductor to the knob of the jar marks the passage of the charge into the latter. The electricity thus conveyed to the interior of the jar by induction acts through the glass, fixing the opposite electricity on the outer coat, and repelling the similar electricity. If a jar be insulated it can receive only such a charge as equals the quantity of dissimilar electricity which can be rendered latent on the outer surface: but if the jar be connected with the ground, the repelled electricity is continuously neutralised, and its decomposition and dissimulation continues till the intensities of the two electricities (of the + and – electricities) are such as to overcome the resistance of the glass when they will combine.

The quantity of electricity which can be accumulated in an apparatus of this kind is proportional to the area of the metallic surface, the thickness and structure of the glass being equal: the thinner the glass, or the more powerful the induction of the electricity through it, the greater the density of the electricity that can be accumulated in it, or the more intense the charge; sometimes the glass is split, or a hole is made in it, when the condensed electricities overcome the resistance it offers to their reunion. To experiment with large quantities of electricity we employ an *electrical battery*, by which we obtain a large amount of surface. Such a battery is generally made by combining a number of jars of a moderate size, their inner and outer surfaces being connected, so that it acts precisely as one large jar would whose metallic surface was equal to that of the whole battery. The outer coatings are connected by placing all the jars in a box lined with tinfoil; their inner coatings by connecting their knobs by means of bent wires. A battery is charged in precisely the same manner as a single jar; that is to say, a stout wire goes from the end of the prime conductor to one of the knobs, and the bottom of the box is connected by means of a chain with the floor; the machine is then set in motion until the charge has acquired its maximum tension: it will be known when this point has been attained, by a hissing noise proceeding from the wires connected with the interior of the jars, and if the room is dark by their luminous appearance; or it may be ascertained by observing when the index of the quadrant electrometer on the conductor stands at or about 90°.

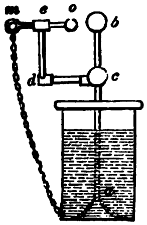
If the outer and inner surfaces of a charged jar or battery be connected by means of a good conductor, the accumulated and latent + and – electricities will combine and neutralise each other instantaneously, emitting at the same moment a spark and a report proportioned to the intensity of the electricity. The length of the spark is measured by observing the distance between the conducting body and the knob of the jar at the time of the discharge.

The Leyden jar, as it is called, was invented by Kleist, (1745,) dean of the chapter at Camin, in Pomerania: instead of tinfoil, the inside was filled with water, and for an outer coating, the wet hands were used. A metallic coating was afterwards substituted. Sometimes instead of lining the inside with tinfoil, the jar is filled with iron filings, or turnings, or the glass is washed with varnish, and iron filings are sprinkled on it. To render the insulation complete, the uncovered part of the glass is washed over with a solution of shell-lac.

Electrical batteries have this advantage over jars of large dimensions, that they can be enlarged or diminished at pleasure, by combining a larger or smaller number of jars, and also that the fracture of a single jar does not put a stop to the use of the whole battery, as would happen if *one* large jar were used. Their size may be very various, it will depend not on the number of the jars, but on the amount of surface they offer covered with tinfoil. The largest batteries ever made were those used with V. Marum's plate-machine (§ 484.); one of these consisted of 225 single jars, each having 1 square foot of tinfoil; it was contained in 15 boxes; another, made afterwards, consisted of 100 jars, contained in 4 boxes, and presented a metallic surface of 550 square feet.

When a number of experiments are performed with jars or batteries in rapid succession, the intensity of the charge may be estimated by the number of turns made by the machine; the usual mode of measuring is, after all, by the length of the spark. To measure this and so at the same time the power of the machine, and also to obtain a number of successive charges of equal intensities, we use *Lune's charging-jar or spark-measurer.* It is a jar of the ordinary size, having a metallic surface of from ½ a foot to a foot (*fig.* 162.), but to the conducting wire *a b* an arm *c d e* is attached, the horizontal part *c d* of which is of glass washed over with shell-lac; the vertical part *d e* is a brass wire having a ring at *e*, in which a graduated bar slides, terminating in a ball at *o*: on this scale the distance of the balls, and consequently the length of the spark, can be measured. To use this instrument connect the end *m* of the bolt by means of a chain with the outer surface of the jar you propose to

Fig. 162.



charge. If the knobs *o* and *b* are placed very near together, a small charge will suffice to combine the + and − electricities of the inner and outer coatings, the intervening stratum of air being penetrated by the spark; but if the distance be increased, then a more powerful charge will be required before the spontaneous discharge will take place. If the same distance is maintained between the balls, the discharge will always happen when the same quantity of electricity has been accumulated. To test the relative powers of two machines, you would place the balls at the same distance, and that would be considered as the more powerful machine which discharged the jar with the least number of turns. Riess used this apparatus as a unit of measure for estimating the intensity of the charge of a battery. For this purpose he insulated the battery, and connected its outer surface with the ball *b* of a Lane's jar, consequently with the interior of the latter. Lane's jar was thus charged with the + electricity repelled from the outer coat of the battery. The number of the charges made by the jar, Riess took as the measure of the quantity of electricity which the battery had received from the conductor of the machine. If the number of discharges made by the jar be divided by the surface charged, the quotient will be the density of the accumulated electricity.

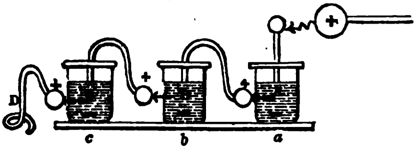
The following simple experiment will render visible the repulsion which takes place in charging a jar:—

First Expt. Powder a glass plate or a cake of resin with semen lycopodii, and insulate the outer coat of a Leyden jar by placing it on this plate. You will observe as each spark goes from the conductor of the machine to the ball of the jar, that the dust lying on the plate of glass is repelled in rays from the periphery of the outer coat of the jar.

In like manner, several jars may be charged by a single one in connection with the conductor of the machine, the electricity driven off from the outer coat of each jar effecting the charge of the next, each of the jars being properly insulated. The following experiment will illustrate this:

Second Expt. Place the jar A (*fig.* 163.) on a plate of glass or Indian-rubber, so that its knob shall be about 1 inch or 1½ inch from the conductor. Insulate the jars B and C in like manner by standing them on plates of glass, *b* and *c*, and bring their knobs as shown in the diagram within about 1 inch of the outer coat of the preceding jar; against the outer coat of the last jar C place a conductor D not insulated. When a spark is emitted from the conductor of the machine to the knob of the jar A, there is emitted a spark between the outer coats and the knobs of the other jars,

Fig. 163.



caused by the + electricity which is repelled, and the conducting body D receives simultaneously the electricity repelled by C, and conveys it away into the ground.

Jars are commonly charged with + electricity; but if it is wished to charge them with negative electricity and the machine has such a conductor, it is merely necessary to present them to the negative conductor instead of to the positive; but in that case the cushion must not be connected with the earth, but in its place the positive conductor must be so connected. A jar may even be charged with negative electricity at the positive conductor by holding it by the wire which has a knob at its extremity, and receiving the spark on the outer coat of the jar, or the jar may be insulated, and its outer coat be presented to the conductor, and its inner one be connected with the earth: in either case it will be seen without further explanation that – electricity becomes accumulated in its interior.

As has been already stated, the discharge of a jar or battery by means of a good conductor is attended with the emission of a strong spark: the discharge may, however, also be accomplished gradually by means of a bad conductor. Alternately touch with any conducting body the inside and the outside of an insulated jar or battery that has been previously charged, and each time you will perceive a feeble spark of free electricity from each coating. These sparks become less and less distinct until the electricities accumulated both inside and outside the jar are neutralised, and the discharge is completed. A jar may also be quickly discharged by presenting to its inner coating, or, what is the same thing, to the knob of the wire that is connected with it, any metallic point or a piece of touchwood. The atmosphere also effects a discharge whose rapidity depends on the moisture of the air. Hence are deduced those precautionary rules which must be observed in the performance of electrical experiments, so as to avoid a needless expenditure of the accumulated electricity.

If several conducting bodies be presented at once to a jar or battery, it will discharge itself by all of them, in proportion to their respective conducting powers; hence, a loaded jar may be discharged with both hands without any very sensible effect, by holding a chain in the middle in the two hands, and discharging the jar by the ends of the chain passed between the fingers.

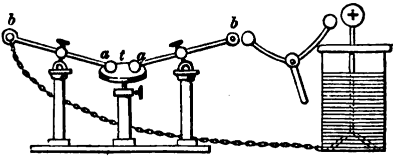
Sometimes it happens, that during the process of charging a jar or battery, it will spontaneously discharge itself; this it will do through the glass at some point where it is unable to resist the tension of the antagonist electricities, which, in their passage through the glass, are occasionally found to make a hole through its substance. A jar that has been thus damaged is useless for electrical purposes afterwards. A spontaneous discharge does not necessarily cause a jar to be pierced, if the stratum of air separating the inner and outer coatings be penetrated by the spark, which will happen whenever the distance between them is less than the length of the spark answering to the charge at that moment contained in the jar.

The following pieces of apparatus are used to effect the easy and safe discharge of jars and batteries: —

1.) *The common discharger*, which is merely a glass handle, at the extremity of which are two bent wires terminating in knobs. They are provided with a sort of hinge, to admit of their being opened to any convenient width. When a jar is discharged, one knob is brought to the outer coat, and the other is made to approach the knob of the jar. To discharg a battery, fasten the chain connected with the lining of th box to one knob of the discharging rod, and bring its othe arm towards some conductor that is connected with the inne coatings of the battery.

2.) *Henley's universal discharger* (*fig.* 164.) consists two copper wires *a b*, which are insulated by being place on two glass pillars; these wires can be moved freely i

Fig. 164.



their sockets, and set at any particular distance apart, so as to convey the charge through any object laid on the little table *t*. The ends *b* are generally in the form of rings, for the sake of hanging chains to them; the knobs at *a* can be removed at pleasure, so that the wires may terminate in points. To discharge a jar or battery by means of this apparatus, attach a chain, which is connected with the outer coating to one of the rings *b*; connect the other ring in a similar manner with one arm of a common discharging rod, and place its other arm in contact with the knob of the jar.

Even after a discharge has been thus made, you will invariably find a greater or less residuum of electricity in the jar or battery. This can be got rid of by repeating the discharge several times, until the electricity which adhered to the surface of the glass has been removed. Riess found that the quantity of electricity lost by the first discharge amounted to $\frac{11}{13}$ of the entire charge.

Faraday and Riess have both, among modern electricians, distinguished themselves by their delicate experiments and their investigations into the nature and properties of electrical charges: the last-named philosopher has, indeed, endeavoured to discover the law which regulates them.

§ 488.

The discharge of a jar or battery is the instant when the elec- ical forces, in their primary state of activity, pass from a state tension into their secondary condition, known as the *electrical rrent.* (§ 473.) The equilibrium which subsisted between the electricities accumulated in the inner and outer coatings of ie jar is destroyed, the two fluids are set in motion, and at that istant their *neutralization* takes place. This electrical action is irried on along the conductor joining the two coatings, and as heatstone has lately shown, by means of a simple experiment, ie movement of the fluids undoubtedly takes place in opposite rections from the two coatings. Hence, in fact, there are two irrents moving in contrary directions; that which issues from ie positive coating is called the *positive* current, that which pro- eds from the *negative*, the *negative* current. As it might cause onfusion to speak of both currents, when our attention will be onfined to one only, we shall say, once for all, that when no par- icular distinction is made, the positive current is to be under- tood.

This current, or the propagation of the state of quiescence, s of so short a duration, that it may be regarded as *momentary*. Wheatstone's experiment has recently furnished us with an approximate measurement of its duration, from which it appears, that in a copper wire it travelled at the rate of 288,000 miles in a second.

The different phenomena which characterize the electrical current, and which we have briefly noticed already (§ 476.), are caused by the neutralization of the ± electricities in all bodies that form parts of the circuit thus instantaneously traversed.

If the circuit passed over by the current of electricity be interrupted at one or more points, there will be a spark at each of these intervals, indicating the direction taken by the fluid. The light is generally white and intensely bright; under certain circumstances it is coloured; its duration can be estimated only approximately by calculation, and is less than the millionth part of a second. We may infer, that sensible caloric is combined with the light, as the spark in its passage consumes substances which can be burnt only by the application of a considerable heat.

If other non-conducting bodies, besides the atmosphere, form a part of the electric circuit, and if the resistance they offer to the combination of the ± electricities be less than the force with which these tend to unite, then the bodies so interposed will be penetrated by the electric spark which, in its passage, will suddenly expand them, or even cause a disruption of their parts. In such cases, the electric spark exhibits, on a small scale, the same phenomenon as the lightning displays on a grand scale in the electrical processes of the atmosphere.

If the ± electricities resume a state of quiescence in conductors which offer an inconsiderable resistance to their combining, they disappear as 0 electricity, without any luminous or thermal phenomenon being developed. If, on the contrary, the conductor has a high retarding power, in proportion to the quantity of ± electricity which is to be neutralized, then the temperature of such a body will be raised, and the greater the resistance it opposes, the greater the heat it will acquire; so that even the hardest substances become incandescent, or are fused, or are even driven off in vapour.

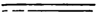
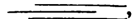
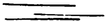
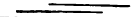
Another purely physical property possessed by the electric current is its power of affecting magnets within a certain distance. This influence is displayed, partly by its disturbing the state of magnetic equilibrium, and partly by attracting and repelling magnetic substances. As the effect produced is only momentary in its duration, these phenomena are not so characteristic of the electric current as when caused by the permanent current which contact electricity generates. For this reason we merely notice the well-established fact, that the momentary electric current has this magnetic property, reserving the closer consideration of the subject to that section of this work which treats especially of electro-magnetic phenomena.

The momentary electric current is further characterized by peculiar physiological effects, exciting convulsive movements in *any living* animal that forms a part of the circuit. At the instant e current is transmitted through the frame the nerves are ex- ted, and the muscles contract with more or less violence, and en after the death of the animal these movements continue to perceptible.

If the current be transmitted through any imperfect conductor, pecially through a moist substance as water, its properties are aterially affected. The spark accompanying the discharge of a r into such a body is short, dim, generally of a violet colour, d unattended by any report. If the human body form a part the circuit, the current excites no muscular contraction, but a culiar pricking sensation. It is remarkable that gunpowder n be ignited only by such a current as this; when a spark is ansmitted from a good conductor, it has no effect on the wder.

Lastly, the current possesses chemical properties decomposing to their constituent elements, such chemical solutions as admit being easily resolved. The effects thus produced are not very werful, as a continued current is required to effect most chemi- l decompositions, and we can obtain only an approximation to by transmitting a rapid succession of sparks through the so- tion we wish to resolve into its elements.

The principal experiments for illustrating the above-named properties of the electric current will be described in § 491—500.

Wheatstone found in his important experiment, that when a Leyden jar was discharged by means of a long copper wire, the continuity of which was interrupted in the middle and also near to the coatings of the jar, that the sparks appeared simultaneously at the ends of the wire, but that in the middle it appeared later. Hence he inferred, that an electrical stream issued at the same instant from both the surfaces of the jar, and that they met a little after in the middle of the wire. The ingenious contrivance Wheatstone then adopted, enabled him to measure the velocity with which the light travelled, and also the time it continued visible. The breaks in the conducting wire of his apparatus were placed in a straight line, so that the break in the middle of the wire was between the other two; exactly opposite he placed a small metallic speculum, in which he could view the images of the three sparks; the mirror was made to revolve with great rapidity about an axis parallel to this line. Now, as the image of an object seen in a mirror appears to be prolonged, if the mirror be turned on an axis, it is obvious that the rotation of Wheatstone's mirror gave to the three sparks the appearance of three parallel lines, which would of necessity begin and end at uneven points, if there were any perceptible interval of time between the images of the sparks being received on the mirror. The important result was now obtained, that when the velocity of the mirror's rotation was small, the position of the lines was even, thus,  ; but when the rate at which it turned was sufficiently accelerated, they assumed this appearance , when the mirror revolved towards the right hand, and  if towards the left; but under no circumstances did the lines stand thus , as they must have done had the current been transmitted from one extremity of the wire to the other; and had its passage occupied any perceptible space of time. From a consideration of these facts, this philosopher inferred that they did not admit of being accounted for on the supposition that a single fluid traversed the wires, but that we must assume that two fluids enter the opposite ends of the conductor at no perceptible interval of time, but that they traverse half the length of the wire in a space of time that admits of being measured.

Again, as according to catoptrical laws (§ 291. S.), the image of an object in a revolving mirror has twice the angular velocity of the latter: it follows, that if the mirror in one second makes *a* revolutions, the image of the spark, supposing it also to last 1 second, would make $2a.\ 360^\circ$. If the image of the spark make an arc of *b* degrees, it would have continued luminous $\frac{b}{720a}$ of a second. When the mirror was made to revolve 800 times in a second, the image of the spark at a distance of 10 feet, appeared to an eye placed close to the mirror, to make an arc of not quite ½ a degree in length. In this case the arc of the spark *b*, must be less than ½ a degree; and as $a = 800$, the duration of such spark must be less than $\frac{\frac{1}{2}}{720\ .\ 800}$, *i. e.* rather less than 0·00000087 of a second. — Of this instantaneous but intensely powerful effect of the electric spark, any person may satisfy himself by looking at a disc by this light; the disc should be made to revolve so rapidly, that the images depicted on it cannot be distinguished with an ordinary degree of light because their impressions become confused in the eye. (§ 347.) Viewed by the illumination of an electric spark, such a disc seems stationary, and the objects painted on it are seen in their true form and position. If one of Newton's coloured wheels (§ 324.) be viewed in the same manner, the individual sectors will be seen of their fundamental colours, notwithstanding its rotation; vibrating cords seem to be in a state of repose in their undulations; and a succession of drops which generally appears to the eye as a connected stream, is seen to be but a series of drops, because the impression of each image lasts for so short a time, that the position of the moving bodies is not altered. The following experiment will confirm what has been just advanced: —

Expt. Place the two balls of a universal discharger (*fig.* 164. *a a*) about an inch asunder; connect one of the wires by a chain with the conductor of the machine, and the other in like manner with the ground. As the machine is turned round intensely bright sparks will pass at intervals from one of these balls to the other. A small Lane's jar may be used instead, and thus a still more intense spark will be obtained. — If a rapid rotation be imparted to a parti-coloured disc, or to a spiral wire held near the place where the discharge takes place, the phenomenon described above will be plainly observed as the sparks are emitted.

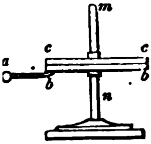
The length of the wire, along which Wheatstone conveyed the electric current, was ½ an English mile; to go over half this distance, or ¼ of a mile, it required about 0·00000087 of a second; whence it follows, that its velocity in 1 second was $\frac{\frac{1}{4}}{0{\cdot}00000087}$ of a mile, or 288,000 miles.

Wheatstone announced his important discovery in 1835, in a lecture which he read before the Royal Institution.

§ 489.

Another kind of apparatus, called a *condenser*, depends, like the eyden jar, on the induction of electricity, and on its being held n a latent state. This instrument is used to detect the presence of lectricity, and to determine its kind in bodies where it exists with o low a degree of intensity, as not immediately to affect the most ensitive electroscopes, requiring to be collected and condensed efore it gains a sufficient degree of tension to cause the elecroscopic bodies to diverge.

Fig. 165.



It consists (*fig.* 165.) of two circular discs of copper or brass, *c c*, *b b*, whose touching surfaces are highly polished, and between which some feeble non-conductor is interposed: this may be either a thin film of air retained between the two plates by three drops of sealing-wax being so placed near the edges of the plates as to keep them asunder; or else their surfaces may be done over with a thin and uniform coat of varish. Pfaff recommends that amber varnish be used for this purpose, as being a good insulator, and less liable to be abraded than other varnishes. The upper plate *c* is called the *collector*, the lower one *b* the *base*. Both are furnished with glass stems *m n*, so that the collector, by means of the handle *m*, may be detached in an insulated state from the base. To connect the base with the ground, attach a chain to the wire *b a*, having a knob *a* at its extremity. — Some bad conductor, such as white marble or dry polished wood, will do for the base instead of metal; the collector then will not require to be varnished, and the connexion of the base with the ground may be dispensed with. Instruments made in this manner act more imperfectly than the others.

The apparatus is thus used: — Place on the collector *c*, or connect with it, the body whose electricity you wish to investigate; touch the ball *a* with your finger: the electricity thus transmitted to the collector acts by induction through the thin non-conductor on the base, and confines its opposite electricity in a latent state, repelling at the same time its similar electricity. As now the base is connected with the ground, a constant supply of neutral electricity is conveyed to it, which in its turn undergoes a similar decomposition. This process lasts until the condenser has received the full charge answering to its surface. Raise the collector, which you lay hold of by its glass stem *n*, suddenly, keeping it parallel with the base, and the latent electricities will be again set free. The electricity of the body under examination will have accumulated itself in the collector, and the dissimilar electricity will be found in the base. Present the collector to any delicate electrometer or electroscope, and the accumulated electricity will be measured.

The most convenient arrangement is, when the base is screwed on the conductor of a delicate electrometer (*ex. gr.*, Bennett's, Oersted's, or Becquerel's, § 480.), in which case the mode of experimenting is slightly different. The body to be examined is put into immediate contact with the under plate *b* (*fig.* 153.), to which, for this purpose the metal pin with the ball is attached, and by means of the finger you connect the condenser with the ground. After the electrical body has remained a sufficient time in contact with the ball *a*, it is to be removed, and the conductor *c* lifted up by its glass stem, by which means the electrometer immediately shows the electricity set free in the lower plate *b*. In this case, the apparatus is exactly reversed from what it was in the other experiment, the lower plate being the conductor and the upper the base; however, the latter may be put in contact with the body under examination, and the lower can be connected with the ground, in which case it is readily seen that the electrometer must indicate the opposite electricity.

Though in most cases a simple *condenser* of the kind described will be sufficient to condense the sensible electricity, or to impart to it the requisite degree of tension, yet this does not always happen. A second condenser with smaller plates must then be used, to which the electricity already accumulated in the greater one may be transmitted and condensed a second time. This *double condenser*, originally invented by Cuthbertson, and since simplified by Peclet, consists of three discs of plate-glass, the whole surface of which is covered over with leaf-gold. The lowest, which we will call *a*, is attached to the conductor of an electrometer, and its upper face is varnished over: the second plate *b* lies on this, and is varnished on both sides. A small copper gilt stem is fastened on one point of its circumference, and in the middle it has a glass handle like a common collector. The third plate *c*, which is to come on this second one, is varnished only on the under-side; it has a hole drilled through the middle, and is furnished with a glass tube which incloses the glass stem of *b*, but is rather shorter than it. This double construction effects the repeated condensation in the following manner: — Lay the body to be examined on the upper plate *c*; touch the middle one *b* so as to establish a connexion between it and the ground; lift off *c*, and touch *a* in a like manner. Replace *c*, touch it again with the body and repeat the former process, until at last, by means of the glass pin, the plates *b* and *c* are lifted up together, when the whole of the electricity accumulated in the undermost plate becomes sensible, as may be seen by the divergence of the electroscopic bodies. Since brass and copper plates can, by the galvanic process, be so readily gilded or covered with platinum, it will for many reasons be advantageous to use such discs instead of glass plates.

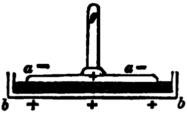
Volta, in 1783, invented this apparatus, which is of great value, as by means of it the existence of sensible electricity has been discovered in many bodies on their being brought into contact with each other, as also in many chemical and atmospheric processes, in which the presence of electricity could not have been detected by any other mode.

§ 490.

The *electrophorus* is also an apparatus invented by Volta, 1775, hich possesses the property of maintaining for a length of time, y its inductive process, the electrical tension which friction had xcited in a non-conductor.

It consists of two principal parts, viz. of a common circular level disc of resin (*b, fig.* 165 *a.*) and a brass plate *a*; the cake of resin which lies in a metal mould, or plate, is the base of the electrophorus; and the brass-plate, which should be perfectly round and smooth, is insulated by means of a glass handle *g*. This instrument is thus used:— The resin is rendered negatively electrical by friction with a cat's skin. The sensible electricity now acts by induction through the mass of resin, which should not be more than ½ an inch in thickness, reducing to a latent state a quantity of + electricity on the opposite side corresponding to its own attractive force; by this means both the − and + electricities may be retained in a latent state for months or even years. If the brass plate be laid on the cake of resin, it also is rendered electro-polar by induction. In this state the following phenomena may be observed in the electrophorus: —

Fig. 165 *a.*



Expt. 1.) Lay the brass plate on the resinous surface, touch it with your finger, and a small spark will be emitted from the brass. This is owing to the − electricity being repelled by the induction of the cake; the + electricity of the brass, on the contrary, is held in a latent state by the − electricity of the resin.

2.) A similar effect follows if the base be insulated, the resin rubbed, and the finger laid on the mould or frame that contains it. In this case it is the + electricity of the mould which is rendered sensible by the induction of the under-surface of the resin.

3.) Touch the brass plate so as to carry off its — electricity, lift it up by the glass handle, by which means it will be insulated, and it will emit another spark. Now the + electricity is rendered sensible, which was before held in a latent state by the resin.

4.) Raise the plate again in an insulated condition by its handle, without previously touching it, and if the apparatus is in good order it will not be at all electrically excited. This is owing to the + and − electricities, which had been kept asunder by the inductive influence of the resin, combining, and thus neutralising each other after the brass had been separated from the resin.

5.) Replace the brass plate, touch the mould with your thumb, and lay one finger on the brass plate, and you will experience a slight shock in your hand. By this contact the — electricity, of the plate being repelled is counteracted by the + electricity of the mould, the antagonist fluid meeting in your hand. Now raise the plate by its glass handle, thus insulating it, and the + electricity it contained in a latent state will be emitted with a spark.

That the dissimilar electricities are rendered sensible in the manner just described, may readily be shown by a Becquerel's electroscope.

From all that has been advanced, it is evident that the lectrophorus acts precisely in the same way as a Franklin's late (§ 487.); it may therefore be charged like it, by conducting r. *gr.* — electricity to its brass plate; the fluid will then adhere to e surface of the resin just as if it had been excited by friction.

An electrophorus may also be used instead of a small electrical achine, as we can draw sparks from the plate when lifted up, fter it has been put in contact with the cake, in precisely the me manner as from the positive conductor of a machine. This ay be repeated indefinitely, by replacing the plate so as to stablish contact between it and the resin, and then removing it: ensure that these surfaces do actually touch, lay a piece of nfoil on the cake, which will cause the sensible + electricity of e mould to combine with the — electricity of the plate each me the latter is replaced. That the electricity of the resin is ot carried off and weakened, may be thus accounted for, that it cts, not by conduction, but solely by *induction* on the neutral lectricity of the brass plate.

The power of an electrophorus depends on the size, hardness, thickness, and polish of the cake of resin, and on the accuracy with which the under-surface of the plate fits it; the most important point to be attended to is the quality of the resin. Robert says that the best composition is 10 parts of gum-lac, 3 of colophon, 2 of white wax, 2 of Venetian turpentine, and ½ a part of pitch; an electrophorus thus prepared will both give out a large quantity of electricity, and will also retain it for a length of time. Pfaff recommends a mixture of 8 parts of colophon, 1 of gum-lac, and one of Venetian turpentine. As a good electrophorus retains for a long time the electricity rendered sensible in it, it is frequently used for igniting a jet of hydrogen gas in Volta's inflammable air lamp.

D. THE PRINCIPAL PIECES OF APPARATUS USED WITH AN ELECTRICAL MACHINE FOR THE PERFORMANCE OF EXPERIMENTS.

§ 491.

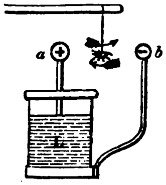
Having become acquainted with the laws of electricity and with its fundamental properties and modes of action, as also with the construction and use of the most important kinds of electrical apparatus, we will now proceed to describe some of the chief experiments in electricity, which may serve to illustrate and confirm the explanation already given. Some of these experiments can be performed by means of the electricity of the conductor of an electrical machine in full work, while others will require a greater quantity of more intense electricity, for attaining which we shall be obliged to use jars and batteries.

I. *Electrical motions* generated by the attraction and repulsion of electricity in a state of tension : —

Expt. 1.) *The dancing figures and pith balls.* The apparatus employed in this experiment consists of a round metal plate (*a a*, *fig.* 160.), suspended from the conductor of the machine ; *b b* is a similar plate placed beneath the other and parallel with it ; *b b* is connected with the ground; *c c* is a glass cylinder between the two. By turning the machine, *a a* becomes + electrified, and *b b* by induction negatively so. Some light bodies, pith balls or pith figures, are laid on the lower plate, and as they become excited they are alternately attracted and repelled. The figures may also be made to dance, by holding a common bell glass over the end of the prime conductor for some time, whilst the machine is in action, and then placing it on a plate containing the figures, the metal plate being in connection with the ground.

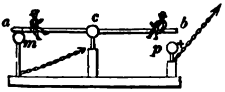
2.) *The electrical spider.* In *fig.* 166., L represents the Leyden jar, to the outer coating of which a wire is attached, having a knob *b* at its extremity. If the jar be charged with positive electricity, *a* is + electrified, and *b* —. Any light substance, such as a spider or other toy, cut out of pith, suspended between these two balls, provided also that it be insulated, will be alternately attracted and repelled by *a* and *b* until the jar is discharged.

Fig. 166.



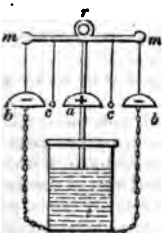
3.) *The electrical see-saw* (*a b*, *fig.* 167.) is a small strip of wood covered over with silver leaf or tinfoil, insulated on *c* like a balance. A slight preponderance is given to it at *a*, so that it rests on a wire having a knob *m* on its top ; *p* is a similar metal ball *insulated*. Connect *p* with the interior, and *m* with the exterior coating of the jar ; charge it, and the see-saw motion of *a b* will commence from causes similar to those which excited the movements of the pith figures.

Fig. 167.



4.) *The electrical bells* (*fig.* 168.) *m m* is a bar of metal, from which three bells, *b a b*, hang, and between them the clappers, *c c*. The bell *a* is attached to a wire, but the other two *b b*, and the clappers *c c*, are suspended by silk threads; the bells *b b* are further connected with the ground by means of chains. This apparatus is either fastened by the bell *a* to the conductor of a Leyden jar, or else it is hung by the ring *r* to a chain attached to the prime conductor of the machine. When the jar is charged, or the machine set in motion, the bell *a* is + electrified, and the other two *b b* are − electrified; hence the clappers *c c* between them are alternately attracted and repelled.

Fig. 168.

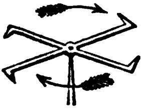


5.) *The electrical cotton.* A hank of cotton, or a downy feather, suspended by a thread from the prime conductor, expands in all directions when the machine is set in action, the fibres seeking for some object connected with the earth. Present a needle or any pointed thing to them, all the ends of the cotton or feather will be drawn together towards it, away from the conductor of the machine; a bundle of silk or glass threads would act in a similar manner. If a person stand on the insulating stool, and lay his hand on the conductor whilst the machine is at work, the hair of his head will stand out in the same way. In this instance the similarly electrified parts of a body are mutually repulsive.

6.) *The electrical shower.* A jet of water from a small Hero's ball or a syphon, insulated and connected with the prime conductor, falls down in a fine shower. A very simple modification of this apparatus is represented in *fig.* 159. *a* is a metal cylinder hung by a chain from the prime conductor; water is poured into it, which is conveyed away by the glass syphon *b*, and the stream is dispersed into the finest rain as it descends, when the machine is set to work.

7.) *The electrical wind.* The flame of a candle held near to a point or small ball attached to the prime conductor, will be extinguished by the current of electricity, caused by the repulsion of the electrified air.

Fig. 169.



8.) *The electrical fly-wheel.* A metal S or cross (*fig.* 169.) turning on a point which is fixed on the prime conductor, or on the knob of a Leyden jar, revolves on the same principle as Segner's water-wheel (§ 165.), or as the steam ball or aeolipila (§ 419.), in an opposite direction to that in which the electricity issues.

§ 492.

II. *Difference observable in the + and − electricities*, shown partly by their luminous appearance, and partly by their mechanical effects.

Expt. 1.) The electricity emitted from a small ball, or from a rounded point attached to the prime conductor, radiates in a stellated form, with a reddish blue light. That discharged from a similar knob or point of the negative conductor is seen as a luminous point or star.

Bring a pointed body near to the positive conductor, and you will have a luminous speck, offer it to the negative conductor, and the light will be seen to radiate in all directions. Hence it appears that wherever one of the electricities is sensible, the other is always attracted to it, and, consequently, that none of the electricity is absorbed in the points which are brought together, but that ± electricities are merely brought into a state of quiescence.

2.) Discharge a positive spark on a polished resinous surface, from the knob of a loaded jar, and on another part of the same surface discharge a negative spark; the + and − electricities will be retained, in a latent condition, on the spots against which they were respectively directed. Now, sprinkle the resin with semen lycopodii, flowers of sulphur, or any similar substance, and particles of the dust will be attracted and retained by the electricities. Blow away the rest of the powder from the surface of the resinous body, and at the spot which was positively electrified, you will see a radiant star-like figure; at the negatively electrified spot there will be merely a round clouded speck. These figures have been called from their discoverer, *Lichtenberg's figures.* — Use of metal rings or bells in electrifying the resinous cake. — Letters or other figures depicted by means of a Leyden jar. — Utility of warming or even melting the surface of the cake before the experiment is performed.

3.) Electrify in a similar manner a cake of resin, positively in some places and negatively in others, and with a soft piece of linen spread over it a mixture of flowers of sulphur and red oxide of lead. The positively electrified spots will be yellow with sulphur, and the negatively electrified will be red with the lead. In consequence of the friction caused by the linen rag, the sulphur attracts the − and the lead the + electricity; the dissimilar electricities are accordingly repelled from those particular spots.

4.) Place two Leyden jars of equal size, the outer coat of one being positively, and that of the other negatively electrified, from 3 to 4 inches asunder on a glass plate, the upper side of which is sprinkled with semen lycopodii, and the under-surface coated with tinfoil. Connect the two inner surfaces of the jars by a common discharging rod, and a spark will be emitted from their outer surfaces. After the discharge, the figures of their respective electricities will be visible in the dust around the jars, and all the dust will be driven away from the path traversed by the spark. This path is generally traced over with positive figures from the positive coating, and with negative figures from the negative coating. These marks disappear near the spot where the two fluids meet, and at the point where the ± electricities combined to form 0 electricity, there is frequently to be seen a large round speck, bounded by no figures whatever.

§ 493.

III. *Electrical luminous phenomena* invariably occur, as we already know, where the ± electricities combine in their passage through the air. They appear as a dim light or glimmer proceeding from the electrified body, when the neutralisation of the two fluids is effected immediately by the air itself, as is the case when a current of electricity is emitted from points or small knobs; but when the current is transmitted through a good conductor, a spark is emitted at every point where the continuity of the conductor is broken. The intensity of the electric light depends partly on the density of the accumulated electricity, and partly on that of the gas through which the spark passes; the denser the medium, and the more intense the electricity, the brighter and shorter will the spark be. In rarefied air the light is longer, broader, and less powerful; it also assumes a rose or violet tinge; its hue is further affected by the nature of the conductor through which the current is transmitted. When sent through gold it is green; through silver, red; through tin or zinc, white; through water, yellow, inclining to orange. On these different peculiarities depends the construction of a variety of electrical instruments, by means of which the most surprising and beautiful luminous effects are produced. Want of space prevents our briefly describing more than a few of the principal.

Expt. 1.) *The spangled rod* is a glass tube some feet in length, on the surface of which spangles of tinfoil are pasted in a spiral form, a small space being left between each spangle and the succeeding one. A spark transmitted along such a conductor appears at the same instant at all the intervals.

The luminous names, stars, and other figures are made on the same principle; they are formed by pasting strips of tinfoil, having breaks in its continuity at the proper places, on a square of glass, along which a spark is sent from the prime conductor.

2.) *The spangled pane* is merely a Franklin's plate (§ 487.), one of whose coats is cut up in small squares. When the plate is being charged, sparks fly in various directions, somewhat like lightning, between the squares of tinfoil; this is owing to the induction of the electricity. When the plate is discharged, the rays from the point where the discharge is effected shoot out like the solar rays.

A *spangled jar* is made by pasting the outer coating in a similar manner, of distinct pieces of tinfoil.

If the spangles be alternately of gold and silver leaf, the sparks will have all the colours of the rainbow.

3.) *The electrical aurora borealis.* — Procure a glass tube, two or three inches wide and a foot or two in length, and close its ends perfectly air-tight with brass caps. A pointed wire should be fixed in the interior surface of each cap; on the outside of one of them there should be a knob, but the other should have a communication closed by a valve, contrived so that it may be fitted on to the plate of an air pump and the air within the tube be exhausted. Connect the knob of the one cap by a chain with the conductor of the electrical machine; and if the tube be set in a vertical position, with that knob uppermost, when the machine is worked there will be a vivid representation of the northern lights, modified according to the degree of rarefaction attained by the air within the tube. If the exhaustion is nearly perfect, the whole length of the tube will be of one violet red colour; if a small quantity of air be admitted, luminous flashes will be alternately emitted from the points fixed to the inside of the caps. As more and more air is admitted, the flashes, which glide in a serpentine manner down the interior of the glass, will become thinner and paler, until at last the electricity ceases to flow through the column of air, when there will be merely a glimmer about the points of the wires. A similar phenomenon may be observed in the Torricellian vacuum of a barometer, if the electricity be excited in the interior surface of the glass by continued agitation of the mercury.

§ 494.

IV. A *phosphorescent light* is emitted by passing a discharge over the surface of many imperfect conductors, especially of such as belong to the mineral kingdom. Opaque bodies, and particularly fruits, are rendered luminous for a short time during the passage of a charge through them.

Expts. 1.) The following substances are rendered phosphorescent for some time by the transmission of an electric spark through them; they acquire various colours, viz.: —

White chalk, phosphorescent, orange.
Rock-crystal, at first red, then white.
Sulphate of barytes, bright green.
Calcined oyster shells, the prismatic colours.
Ditto, with sulphur, a steady bright light.
Amber acid, green.
Loaf sugar, green.

Henley's universal discharger will be found extremely convenient for performing these experiments. The substance through which you wish to pass the charge is to be laid on the stand between the wires *a a*, *fig.* 164., connecting them at the same time with a Lane's jar, *fig.* 162., having a surface of a square foot, or a foot and a half. These two pieces of apparatus will be found of great service in the following experiments: —

2.) Place a small melon, citron, apple, or any similar fruit, on the stand of the discharger; arrange the wires so that their ends are not far asunder, and at the moment when the jar is discharged the fruit becomes transparent and luminous.

One or more eggs may be treated in the same manner, if a small wooden ledge be so contrived that their ends may just touch, and the spark can be sent through them all.

Send a charge through a lump of pipe-clay, a stick of brimstone, or a glass of water, or any coloured liquid, and the entire mass of the substance will for a short time be rendered luminous.

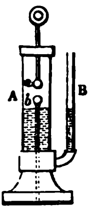
As the phosphorescent appearance induced is by no means powerful, it will be necessary that these experiments should be performed in a dark room; and indeed the effect of the other luminous electrical phenomena will be heightened by darkening the room.

§ 495.

V. *Mechanical effects of the condensed spark discharged from a Leyden jar, or an electrical battery.* — The electric current exerts a considerable mechanical force, in its passage to a good conductor, through such bodies as are either-non-conductors, or bad conductors of electricity, expanding, splitting, piercing, or dispersing hem. If these bodies are liquids, as air or water, their particles are thrust aside; and if contained in vessels, the effect produced s the same as if they had suffered a momentary expansion.

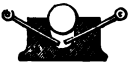
Expts. 1.) *Kinnersley's electrical thermometer* (*fig* well adapted to show the momentary of the air when penetrated by a charge. The glass tube, A, is air- communicates with B, which is ope a coloured liquid stands at an equal the two tubes. When a spark passes b, the liquid in B will be seen to r instant.

Fig. 170.



2.) Close the aperture in a smal vessel, by inserting a cork or a wood that fits exactly; let ther wires passed through, whose points a quarter of an inch asunder; t charge along them, and the co forcibly projected.

Fig. 171.



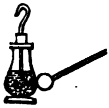
3.) Fill up the cavity of cup, mentioned in the precedi ment, with sand or gunpowder passage of the spark will be fou perse the latter in all directions.

4.) Water suffers so sudden an expansion that t tubes are burst if filled with it, and a spark is t through the tube, from a wire at one end, to a si almost meeting it from the other end.

5.) Place several cards together between the l universal discharger, along the wires of which sen from a jar presenting a surface of not less than o foot; if the charge be pretty strong, the spark through all the cards, which, if held to the no found to have a peculiar odour of sulphur and rus, like that which may be perceived in places little time after they have been struck with lightni and other imperfect conductors may be penetrate manner. Lay a piece of writing paper on the st universal discharger, placing its knobs on the pape tance of one or two inches from each other; the the charge, and if the paper was dry, it will be fou been torn asunder by the passage of the spark.

6.) Fill a small vial with oil, close it with a cor which a wire passes, the lower end of it being s to touch the inner surface of the gl other extremity of the wire, whic above the cork, is formed into a hoo bottle may be suspended from the p ductor. Set the machine in motion a metal ball opposite to that part

Fig. 172.



which is touched by the wire within, and the spark, in its passage through the glass, will make a hole.

7.) Lay a piece of tinfoil, in which there are several holes, between two small boards, or two panes of glass; screw them tightly together, and transmit a pretty strong charge through the metal. On releasing the boards, or the pieces of glass, they will be found to be split.

§ 496.

VI. *Excitation of heat by the electric current.* — This is shown ually when the current is transmitted through fine wires and hen a spark passes through any combustible substance. In the st case the effect is generally greater, the greater the resistance fered by the wire, and the more powerful the charge given off om the jar or battery; in the second, the effect depends princilly on the readiness with which the body is put in a state of mbustion, as many substances are ignited by feeble sparks, hilst others can be burned only by powerful ones.

Expts. Stretch a piece of very fine harpsichord wire between the arms of a universal discharger; if your battery is strong enough, you may use a piece of watch-spring. Send a powerful charge through the metal, and it will be either raised to a state of incandescence, or it will be melted. If the charge is not sufficient to fuse the wire, the increase in its temperature will be marked by its becoming blue.

If the wire be the same, the length of it fused by any particular charge will depend on the surface of the battery and on the intensity of the charge; that is to say, on the quantity and density of the electricity set in motion *: equal charges will therefore melt equal lengths of the same wire. In wires of different metals but equal diameters the length varies, and the better conductor any body is, the shorter the length that will be melted. Priestley and V. Marum tried by this means to ascertain the different conducting powers of different metals, but the results they obtained are deficient in accuracy. More recently Riess has performed some very exact experiments, by which he measured the temperature of a piece of platinum wire, forming part of the electrical circuit, with a very delicate electrical air thermometer that he constructed for the purpose. The principal laws which he by sending it through a damp conductor. Hence we are enabled to ignite gunpowder, which resists the action of the spark under ordinary circumstances. (See *Third Expt.* § 495.) Place some gunpowder in the little wooden cup (*fig.* 171.), and carry the spark along a moist thread 6 or 7 inches in length, attached to that arm of the universal discharger which is connected with the negative coat of the jar containing the charge, and the spark in its passage from the end of one wire to that of the other will cause the powder to explode.

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* A Lane's jar, having a surface of tinfoil of 9 Vienna square feet, = 9·68 English, was so powerfully charged by 14 turns of Pfister's plate machine §484.), that its spark melted a piece of steel wire, No.12., 18 inches in length; nd V. Marum's great battery, of 550 square feet, fused an iron wire $\frac{1}{40}$th of an ch thick, and 24$\frac{1}{2}$ inches long, throwing it off in little red hot globules.

§ 497.

VII. *The magnetic effects* of the electric current are variously displayed; but, as has been already (§ 488.) remarked, the influence exerted by the interrupted and momentary currents of frictional electricity is less perceptible than that of the continued current, generated by electricity by contact, and by thermo-electricity. Its most remarkable feature is the excitation of magnetism in unmagnetized steel, and its inversion of the poles in magnets. A few experiments illustrative of these properties will now be given: —

Expts. 1.) Place a strip of copper-plate, about 1 or 2 inches in length, between the arms of the universal discharger; transversely to it, and supported by any insulator, lay a fine sewing needle, and pass through it some pretty strong charges from a jar. The needle will have become magnetic, that end which lay to the right of the electric current being a north pole, and the opposite end a south pole. Place the needle beneath the copper, and the needle's polarity will be reversed.

2.) Place a small variation needle on the strip of copper, so that the latter shall intersect its magnetic meridian at right angles; send some powerful charges through it, from west to east, and the magnet's polarity will be reversed: this effect will not obtain if the charges are transmitted from east to west.

3.) Steel needles may be magnetized with greater certainty, if the electric current be insulated and conveyed by a helix around the needle. This will be best effected by placing the needle in a spiral of copper wire covered over with silk, the ends of the helix are to be in contact with the arms of the discharger. The single spark from the prime conductor exerts a sensible effect; but if a charge be sent from a loaded jar, the magnetism will be still stronger. Lay a magnetized needle in the helix, and conduct the electric current, so that the north pole of the needle shall lie on the right hand of the direction in which the current moves; and after a few charges the needle's pole will be reversed.

An explanation of this phenomenon will be given in the section on Electro-magnetism.

§ 498.

VIII. Its *physiological effects* are developed by electricity hen in a state of tension: they appear to be owing, in part at ast, to the induction of electricity taking place in the human ame. Among those effects may be enumerated the sensation f a spider's web being drawn across the face, and the emission of hosphoric odour. They are felt most powerfully in those parts f the body which form a part of the circuit through which the ectric current passes, by a shuddering sensation, and a contraction of the nerves and muscles, known as the electric shock.

The effects of the shock vary with the extent of the surface covered with tinfoil, and they may become so intense as to cause transient or permanent lameness in particular limbs, nay, even death itself. In performing these experiments, care should be taken that the charge is not too strong. — The discharge from a single jar is sufficient to kill small animals; and a battery of 13 feet coating is enough to stun or even to destroy life in a large animal, especially if the stroke be conducted through the skull.

The conduction of the successive and momentary currents through parts of the animal organization produces a contraction of the nerves and muscles, by which the activity of the vascular system is increased, the motion of the fluids accelerated, and the animal heat raised. Hence frictional electricity has been frequently applied in medical practice.

Electricity produces on vegetables, effects closely resembling those just described in the case of animals: conduction appears to exert no perceptible influence on vegetation; but if a charge from a jar be sent through plants it proves fatal to them.

Expts. 1.) *The electrical bath* is administered by placing a person on an insulating stool, and directing the electric current from the conductor to different parts of the body by means of some pointed conductor.

2.) *The electric shock* from a charged jar may be given to a number of individuals at once, if they lay hold of each other's hands, the last person in the circle putting himself in contact with the outer coat of the jar, and the first touching the knob of the jar, by which means the circuit will be completed. On account of the velocity with which it travels the shock will be experienced simultaneously by all. —In-from the necessity that the amalgam applied to the cushions of the electrical machine should be a very oxidizable body. To this it may be objected, that it yet remains to be proved that this peculiar odour is necessarily connected with the development of electricity; and that the oxidation of the amalgam is not an indispensable requisite, has been shown by Sir H. Davy's experiments, for he found that a small electrical machine in an atmosphere of hydrogen, carbonic acid gas, and other gases, gave out as much electricity as when worked in the common air; indeed, in the carbonic acid gas it yielded more. According to a still more recent theory than the above, it has been held, that a peculiar motion in the molecules of the bodies rubbed together is the true source from which the electricity is derived. This hypothesis has as yet been but partially received, and the discovery of an explanation, both general and satisfactory in its application, is an object still to be desired.

> Schönbein has performed a number of experiments, in order to detect the properties of the odour emitted during the action of an electrical machine (§ 485.), which, in the case of the cards penetrated by the spark, bears so striking a resemblance to the blasting of objects by lightning. (*Fifth Expt.* § 495.) This philosopher thought that he could recognize the odour in the decomposition of water by the electric current. He accordingly gave it as his opinion, that this odorous principle, which he called *ozon*, was a body contained both in air and in water, that it had hitherto escaped the observation of chemists; and that, under certain circumstances, this element was set free by electricity. De la Rive, on the contrary, holds that this odour is caused by extremely minute metallic particles with which the electric fluid is charged; and which, when water is decomposed, are given off with the oxygen in the atmosphere.*

III. ELECTRICITY BY CONTACT, GALVANISM, VOLTAISM.

A. *Of the Electricity elicited by the Contact of Heterogeneous Bodies in general.*

§ 501.

The state of electrical quiescence in two heterogeneous bodies, which are good conductors of electricity, is destroyed by bringing em into contact with each other. Separate them in an insula-d condition, and one will be found to be + electrified, and the her — ; but this state of tension is often so feeble that its exist-ce can be proved only by the aid of a condenser.

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* Professor Schönbein read a paper on "Recent Experiments on Ozon," at the 15th meeting of the British Association in June last. From these experiments it appeared that the smell was always developed at the + pole; that it was capable of being preserved in closed bottles; that heat destroyed it; and that many of the metals had also the same power. Although at first supposed to be an elementary body, it may now be looked upon as, in all probability, a trit-oxide of hydrogen. An analysis of the professor's paper may be found in the Athenæum for July 6. 1845.

Volta, towards the end of the last century, first discovered is peculiar excitation of electricity in the metals. *Volta's funda-ntal experiment*, by which the existence of this species of elec-city may be verified, can be variously performed.

First Expt. by means of the condenser. Place in immediate contact two polished discs, one of copper, the other of zinc, holding them by means of glass handles, so that they may be insulated; separate them, and convey the sensible electricity of one of the plates to a condenser. (§ 489.) Touch both the plates with the hand so as to carry off their electricities: repeat the contact and separation, and, as before, convey the electricity of the one plate to the condenser. Repeat this eight or ten times until you have sufficiently charged the condenser, which will be loaded with + electricity, if you have touched it with the zinc plate, or with — electricity if with the copper one. The electricity thus accumulated by conduction on the condenser, may be tested by means of a delicate electroscope. To avoid exciting electricity by touching the metal of the conductor with the plate, which would affect the accuracy of the experiment, as we profess to obtain the electricity merely by the contact of the zinc and copper discs, a piece of moistened blotting paper should be laid on the plate of the conductor, and the disc should be made to touch this paper, and not the metal of the conductor itself; or the condenser, may be furnished with two plates, one of zinc and the other of copper, and when the electricity is conveyed to the condenser, these should be changed, so that the like metals should always be brought together. Peclet's double condenser will still more effectually secure this object. (§ 489.)

Second Expt. without the condenser. Screw a perfectly smooth plate of pure copper, about 2½ or 3 inches in diameter, on to the conductor of a Becquerel's electroscope, or of a delicate Oersted's electrometer. Now, on it lay a similar disc of pure zinc, of exactly the same size, and the two plates will, by contact, be oppositely electrified. While this contact is maintained, the ± electricities will be held in a latent state. Remove the zinc plate by a glass stem, which insures its being insulated, raising it perpendicularly from the copper one, and the electroscopic bodies will show that the copper plate is negatively electrified. The + electricity of the zinc plate will be verified by presenting it to another electroscope standing near the former; or, without a second or, better still, a delicate electrometer on Oersted's construction. (§ 480.) The deviation of the needle in the last named instrument enables us with tolerable accuracy to compare the difference in the electromotive tension of any two bodies. The metals to be subjected to this test should be of a circular form, from 2 to 3 inches in diameter, and at least 2 lines thick. As silver, gold, and platinum plates of this size would be very expensive, brass plates may be used instead, covered with gold, silver, or platinum, by the process of electroplating. (§ 519.) A circular hole is made in the centre of each of these discs, for the purpose of connecting them with the conductor of the electrometer, or for inserting glass stems by which they may be insulated. The plates must be as highly polished as possible, and the metal should be perfectly pure. The zinc or platinum plate, as being the extremes in the table, is to be screwed to the conductor of the electrometer, and the others are to be brought into contact with it in the manner described in the second experiment of the preceding paragraph. To investigate any two metals, say iron and silver, all that is requisite is to place one of them on the plate of the conductor, to insulate the other, and place it on the former.

If several different electromotors are brought into mutual contact at once, as *ex. gr.*, A with B and B with Z, then this remarkable result ensues, that whatever electromotor B may be, A always has the same kind of electricity, and of the same intensity, as if it had been in immediate contact with Z, without the interposition of B. Further, if instead of B we interpose any number whatever of opposite or similar electromotors between A and Z, as A, B, C, D . . . Z, A continues in this case also to be electrified precisely as if it were in immediate contact with Z.

For the sake of illustration, we will suppose the relative difference of tension between A and B = 5, between B and C = 1, between C and D = 3, between D and Z = 7; then the difference of tension between any two members of the series is invariably equal to the sum of the differences of the intermediate links. Hence, between A and C 5 + 1 = 6, between C and Z = 3 + 7 = 10, and between A and Z = 5 + 1 + 3 + 7 = 16.

§ 503.

The electromotive force can, moreover, be excited not only between the solid conductors of electricity, but also between them and conducting liquids. With respect to the species of electricit excited by the contact of the various metals with different liqui

dies, the numerous experiments of Pfaff have conducted us to
e following results:—

1.) *The alkaline liquids,* as caustic potash, caustic soda, am-
nia, generally excite in the metals a state of *negative electrical*
sion, the intensity of which is greater the nearer the metal is
the positive end of the series. To this rule, however, there are
me exceptions. When in contact with these liquids, tin, anti-
ony, zinc are the most powerful; platinum, bismuth, silver,
e most feeble electromotors.

2.) *Concentrated acids,* as nitric acid, sulphuric acid, &c., im-
rt to metals the opposite, that is to say, the *positively electrical*
sion; and in particular *all the metals,* without exception, when
ted on by concentrated nitric acid, become *positive.* In this
id, steel, cast iron, pure iron, and platinum are the most powerful
ectromotors, and zinc the feeblest. With sulphuric acid they
e divided into two classes; those metals, as gold, platinum, cop-
er, which stand near the negative end of the series, becoming
sitive; the others, antimony, tin, and zinc, being *negatively*
ectrified. The same rule holds good with regard to hydro-
loric acid.

3.) *In diluted acids and solutions of heavy metallic salts,* the
aracter of the electrical tension for the most part depends
n the order of the metals in the series. Considered as a whole,
ey are *negatively electrical* towards these liquids, the more posi-
ive metals being the most intensely negative, the negative ones
ss negative, showing an increasing tendency to become positive;
nd those which are the most negative when acted on by these
iquids actually acquire a positive tension. The *solutions of an*
lkali with sulphuric acid present the striking anomaly of rendering
he negative metals *most powerfully negative.*

From a consideration of these facts it was inferred, that the
iquids received exactly the opposite electricity to that acquired
y the metals immersed in them, and that the intensity of their
ensions corresponded.

4.) In most of the liquids, the metals, as a whole, invariably dis-
lay the like excitation, but the original difference in the tension of
hose whose surfaces are chemically acted on by the fluids decreases,
nd is at length converted into the opposite kind to that which
hey had at first.

Pfaff, to whom the scientific world is under considerable obligations, modified in various ways the experiments which led to the results we have just developed: *ex. gr.* he procured strips of the different metals, and laid on them similar pieces of pasteboard saturated with the liquid he wished to examine, and connected the metal with the collecting plate of the condenser by laying under it a piece of blotting-paper soaked in distilled water, the upper strip of pasteboard being and it will be found to retain its original electricity, though in a less degree, and with an intensity corresponding precisely with the difference of the electromotive tensions of the two metals. (§ 503. 3.) (a) Immerse two strips of the same metal in a liquid, and both will be equally electrified; no difference will exist between their tensions. (b) But if the fluid polarize the metal placed in it, we shall obtain an effective battery with a single metal, by immersing one of the plates before the other, as is done, for instance, when iron and platinum are brought in contact with a solution of caustic potash. In proportion as the polarization of the second plate proceeds, the difference in the tensions of it and the plate first immersed diminishes, until after some time it ceases altogether. The difference in the tensions of any two metals will be increased, for obvious reasons, if the liquid in which they are plunged excites in one a condition of positive, and in the other of negative electrical tension, as happens when zinc and copper are immersed in concentrated sulphuric acid. (§ 503. 2.) *Fig.* 175. represents an arrangement of this kind, both copper (C). and (Z) being immersed in the acid (S_3). For similar reasons, an opposite electrical tension will be produced if two homogeneous metals be connected together, and placed in two different electromotive fluids, the metal in the one being negatively electrified, and that in the other positively. As an illustration, we may immerse one piece of platinum in an alkaline solution, and another in concentrated nitric acid; or immerse two plates of iron, one in sulphuric acid, and the other in concentrated nitric acid. (c) (§ 503. 1 and 2.) A scheme of this is given in *fig.* 176., (*Pt*) being the platinum, (A) the alkali, (*a c*) the acid, and *a b* the porous material between the liquids. The most intense electromotive tension is excited by employing two heterogeneous metals and two similar liquids, the one metal being immersed in that fluid which renders it the most powerfully negative, and the other in that which renders it the most powerfully positive, the fluids themselves being connected by interposing a porous partition betwen them. Such a

Fig. 175.

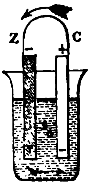


Fig. 176.

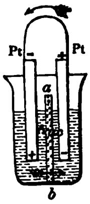
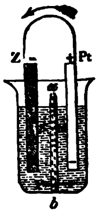


Fig. 177.



mbination is effected thus, as shown in *fig.* 177., by placing atinum (*Pt*) in concentrated nitric acid (N_6), and zinc (Z) in ncentrated sulphuric acid (S_3). (d)

(a.) Suppose copper and zinc were placed together in a dilute acid, and that the zinc, as the more powerful electromotor, acquired a tension of -3, whilst the copper was merely -1, the difference between their tensions would therefore be $=2$. Connect the zinc with the ground, and the copper would show on the condenser a tension of $+3-1=+2$; if the copper be similarly connected, the tension of the zinc will be $+1-3=-2$.

(b.) Immerse two strips of zinc or copper in the same acid, and the maximum tension of each strip of zinc will be -3; that of each strip of copper -1, the difference of tension in either case $+3-3$, or $+1-1=$ nil

(c.) Now immerse a plate of iron in sulphuric acid and another in concentrated nitric acid; then the former will have a negative tension, say of -2, and the other a positive one of about $+4$; the difference of the tensions between these two homogeneous metals will $=6$. Let there be a conducting medium between the two fluids, connect the iron in the nitric acid with the condenser, and the plate which is in the sulphuric acid with the ground; then the former acquires a positive tension of $+4+2=+6$; reverse the arrangement, and the iron in the sulphuric acid acquires one of $-2-4=-6$.

(d.) In like manner we obtain the tension resulting from a combination of two heterogeneous electromotors with two different liquids, as *ex. gr.* of zinc with sulphuric acid and of platinum with nitric acid. If in the case supposed the tension of the zinc be -3, and that of the platinum $+5$, then the difference of their tensions is 8; connect the zinc with the ground, and the platinum will have a positive tension of $5+3=+8$; and if the platinum be so connected, then the zinc will have a negative tension of $-3-5=-8$. These batteries may, however, be so combined, that the two heterogeneous electromotors may acquire a similar and equal tension from the liquids in which they stand. In such a case the tension of each electromotor equals the difference between their tensions, viz. nil. This will happen if zinc be immersed in a dilute acid, and platinum in a solution of some alkali with sulphuric acid.

The difference in the tensions of the electromotors immersed in a fluid has been explained by assuming that the electricity originally excited in each by contact with the fluid acts by induction or polarization on the particles of the fluid lying between the two plates in such a manner that every such particle acquires an equally intense electricity, but of an opposite character to that of the metal on the sid nearest to each of the metals; while on the side more remot it acquires a similar and equal electricity to theirs, so that th ends of the circuit formed by the liquid which touch th other metallic surfaces excite the opposite electrical tensio or polarization. A reference to *fig.* 178. will render th

Fig. 178.

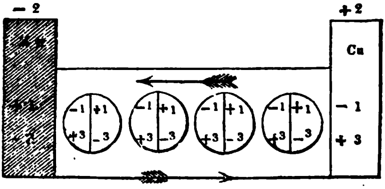
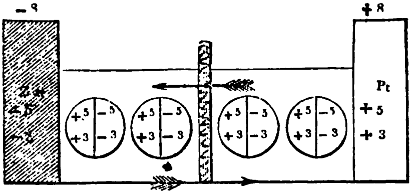


Fig. 179.



more easy to be understood than a long verbal descript Z *n* is a zinc and C *u* a copper plate, connected in a cir by the particles of the fluid. Now suppose the ten excited by the fluid on the zinc alone were – 3, then polarization produced in the liquid by this metal woul expressed by the lower row of numbers contained in circles representing the particles of the liquid; and if tension it would have caused in the copper alone be then the upper numbers will mark its polarization by metal, and the result of this double induction of electr would be that the tension of the zinc would be – 2, and of the copper + 2. — *Fig.* 179. represents a similar bination of a zinc and platinum battery with sulphuric nitric acid, the zinc acquiring the negative, and the tinum positive electricity.

Such combinations of solid electromotors with suitable liq constitute *simple hydro-electric* or *voltaic batteries.* Of these t are three principal varieties.

ries *consisting of two heterogeneous electromotors with* These were the earliest invented by Volta; and until were almost the only ones in use. They are com- of zinc and copper plates immersed in either dilute e saline solution.

ries *of one homogeneous metal with two heterogeneous* o this class belongs Becquerel's hydro-electric battery, d, in which platinum (see *fig.* 176.) is put in contact ion of caustic potash, or with concentrated sulphuric er and Wöhler's batteries are also made on a similar e same metal in the former of these being immersed , and in the latter in concentrated nitric acid. The f tension in a Becquerel's battery is far less than in 1.) This instrument has served no other purpose blish the fact, that a state of electrical tension can be contact with two heterogeneous fluids. The *iron* ch more effective, as the polarization of this metal in rated nitric acid causes a very considerable degree of

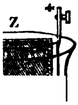
ries *combined of two heterogeneous electromotors with t liquids:* these are a recent discovery, and are the ve of all the varieties; *i. e.* by means of them the difference of tension between the electromotors is Among this class we may name *Daniell's zinc and ry*, in which zinc stands in contact with sulphuric opper with a solution of sulphate of copper; *Grove's atinum; Sturgeon's zinc and iron;* and *Bunsen's zinc batteries*, in which the zinc is placed in contact with cid, the platinum, iron, and carbon with concentrated

construction of these batteries admits of various ations; from which, indeed, the different names they e for the most part derived.

Single-fluid batteries. Volta's battery consists of equal of copper and zinc, between which are laid pieces nel or paper of the same size, soaked in the exciting

Vollaston's battery (*fig.* 180.) the zinc plate is surrounded by the copper one, which however does not immediately touch it at any point, there being a space of ¼ of an inch or thereabouts all round between the two. The two plates are to be immersed in the exciting fluid.

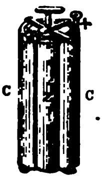
180.



Oersted's trough apparatus is essentially the same with the preceding battery. It consists of a trough of copper plate, in the form of a parallelopiped, about ½ an inch wide at the bottom; in it the zinc plates are arranged so as not to touch the copper; the trough serves also to hold the liquid.

Hare's spiral battery (*fig.* 181.) consists of two zinc and copper plates of equal length, rolled together in a spiral form, so that they are about ¼ of an inch asunder. Their parallel position is given to the spirals by means of a wooden cross at top and bottom, with notches into which the plates are fastened. Both crosses have a common axis. There is a handle at top, and to each of the metal plates is attached a mercury cup + and —. This combination is then set in a glass cylinder large enough to receive it, in which the liquid is placed. This apparatus has one advantage, that metal plates of a considerable size can be used without their occupying much room.

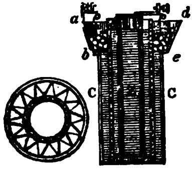
Fig. 181.



Faraday recommends, to ensure a powerful action of these batteries, the use of a mixture of 200 parts of water, 4½ parts of sulphuric acid, and 4 of nitric acid. If the effect is desired to be less violent but more permanent, he recommends a solution of common salt, or a mixture of sulphuric acid, with from 20 to 30 times its quantity of water. The electromotive power will be increased and rendered more constant by amalgamating the zinc, which can be accomplished most readily and cheaply in the following manner:—First, immerse the rough zinc plates in a weak solution of sulphuric acid, containing from 6 to 8 times as much water as acid, until the thin film of oxide is dissolved; then wash them with water and place them in a dilute solution of nitrate of mercury. After a short time there will be found on the surface a perfectly uniform amalgam of zinc; when this is formed, wash the plates with water and rub them with sawdust.

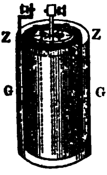
2.) *Batteries with two different liquids.* In these the two liquids must be so placed as to establish conduction without their being allowed to mix. This is best effected by interposing some porous substance between them; thin cylindrical cells of porous porcelain, slightly baked, answer best. Place a cell of this kind in a cylindrical glass, an inch or an inch and a half wider than it in diameter; in the earthen cell, place one electromotor with its appropriate liquid, and in the glass vessel the other with its liquid, taking care that the two electromotors are not more than from ⅛th to ¼th of an inch from the walls of the porcelain cell.

Fig. 182.



A sectional view is given in *fig.* 182. of the most advantageous arrangement of a Daniell's battery. c c is a copper cylinder with bottom, rather wider at top, as *a b* and *d e* show (the outer glass vessel is not required with this construction); *p p* is the porous porcelain cell, in which the amalgamated zinc cylinder stands. Pour a saturated solution of sulphate of copper into the copper cylinder. That the action of this battery may be constant, the strength of the solution must be maintained. For this purpose two concentric rings of copper wire connected together by zig-zag wires fit round the porcelain cell, and rest on *b* and *e* against the copper cylinder. On this net-work such a quantity of the copper crystals is to be laid, as by their gradually dissolving will maintain the liquid at its required strength, and so repair the waste caused by the working of the battery. If violent action is desired, use 1 part of concentrated sulphuric acid to from 4 to 9 parts of water; if moderate action, 1 part of sulphuric acid to from 50 to 100 of water.

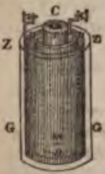
Fig. 183.



In *Grove's battery* (*fig.* 183.) the amalgamated zinc cylinder z z stands in a glass vessel; inside the zinc is placed the earthenware cell *p p*, intended to receive the platinum. Leaf platinum will be found the most convenient, and to save expense it may be had thin. To ensure at the same time a large surface of this metal, and action on both sides, Grüel's arrangement may be adopted. The leaf platinum is attached by means of wires of the same metal to a central stem, so as to form four or six flaps; the whole has one common conductor. Poggendorf recommends as a more simple contrivance, that the leaf of platinum be about half as broad again as the diameter of the porcelain cell into which it may be made to go by bending it in the form of an S. By this means, all cutting and fastening of the platinum will be dispensed with, except only fastening it to the wire which is to serve as the conductor. Pfaff employed a porcelain cylinder coated with platinum, instead of a leaf of this metal. This will be rather cheaper than the metal itself, but as far as my experience goes, these cylinders are less effective than an equal surface of platinum, and I have used the cells both from the manufactory at Copenhagen, and also from that at Meissen. The liquid used to act upon the zinc is sulphuric acid diluted with from 4 to 9 parts of water; that on the platinum, nitric acid whose specific gravity is 1·33.

In *Bunsen's battery*, charcoal is substituted for the expensive substance, platinum. For a length of time, attempts had been made to use for this purpose graphite (plumbago) in its natural state, and also the masses found in gas retorts; but the difficulty with which portions could be met with of sufficient size and of convenient form, imposed an insuperable obstacle. Professor Bunsen has, however, succeeded, by repeatedly heating a mixture of pulverized coal and coke, in obtaining a strong porous mass, which, as regards its conducting and electromotive powers, is fully equal to platinum; it can easily be worked and made to assume the required form. Bunsen has variously constructed his batteries; one of the simplest combinations, perhaps, is the following, which nearly resembles Grove's. (See *fig.* 184.) C is the carbon cylinder, substituted for one of platinum, standing in a porcelain cell *p p*, whose diameter is 3 or 4 lines longer than that of the carbon. *p′p* is enclosed in an amalgamated zinc cylinder z z, whose diameter is about two lines greater than that of the earthenware cell. The whole is placed in a glass G G about an inch, or an inch and a half wider than the earthenware. Drill a hole *m n* in the carbon, to within an inch and a half of the bottom, and about one third of its diameter in width. Into this cavity concentrated sulphuric acid is to be poured, by which the porous mass will soon be penetrated. Fill the interval between the earthenware cell and the carbon cylinder with the same acid. A copper ring *r*, which fits the latter tightly, serves as a conductor. The zinc is acted on by sulphuric acid, with from 4 to 9 parts of water. Bunsen has since modified his battery, by making the carbon cylinder open at bottom, and of sufficient size to contain the earthenware cell in which he places the zinc element.

Fig. 184.



With equal surfaces, the powers of a platinum and carbon battery are nearly equal. They are both far superior to a Daniell's constant battery. Jacobi says 6 square inches of platinum in a Grove's battery are equal to 100 inches of copper in a Daniell's battery. According to my own experiments I found, that to produce equal effects, it required 16 times as great a surface of copper as of platinum; and in a spiral battery, on Hare's construction, I found 340 times the surface of copper was needed to that of platinum to insure equal effects.*

Now, although Grove's and Bunsen's batteries are more powerful than Daniell's, yet the latter has this advantage over them, that its action is the most constant, its electromotive force being but little impaired by the battery's being kept at work for a whole day. There is this additional inconvenience connected with the use of both the platinum and carbon batteries, that the nitric acid used in them, in proportion as it is concentrated, becomes converted the more rapidly and profusely into nitrous acid, the vapour of which is both prejudicial to the breath and injurious to many sorts of apparatus. In platinum batteries this evil may, in some degree, be remedied by means of a lid, made to fit the earthenware cell. In the carbon batteries it is less easy to apply this remedy. Warrington and Dr. Leeson substituted for the sulphuric acid a liquid composed of 3 parts of bichromate of potassa, 4 of concentrated sulphuric acid, and 18 of water. Poggendorf says that he found the electromotive influence it excited in a carbon battery equal to that produced by sulphuric acid, but that its character was less steady and permanent; when used with platinum batteries, he says, it is far less effective than sulphuric acid.

§ 506.

The tension excited between the electromotors of any simple
taic arrangement is, after all, very feeble. Its intensity may,
vever, be increased by connecting several of them together; a
covery which has immortalized Volta's name. A combination
this kind is termed a *compound hydro-electric battery*, or a
taic *pile* or *battery*; sometimes it is called a *galvanic battery*.
constructing it, the like metals in the individual batteries
st all be ranged one way; as for instance, all the copper on
left hand and all the zinc on the right: and in this order the
erogeneous metals must be joined by a good conductor, or else
y must be placed in immediate metallic contact.

The essential form of such a combination may be represented in the annexed diagram:

$$C\,l\,Z \frown C\,l\,Z \frown C\,l\,Z \frown C\,l\,Z,$$

C being the copper, Z the zinc, and l the intermediate liquid, $\frown$ represents the metallic connection or contact.

The individual members of these compound batteries

Note. Mr. Walker in his Treatise on Electricity expresses his esti-
of the comparative merits of Platinum and Carbon, in the following
manner.—"Platinum *is in the long run decidedly preferable to Carbon*:
perience will soon teach."

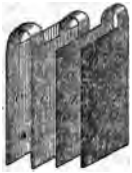
may be variously arranged according to the nature of the single batteries of which they are composed. The following are the chief: —

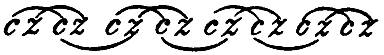
1.) *Single-fluid batteries.* — The oldest of all, invented in 1800, and still in frequent use, is named after its inventor, the *Voltaic pile.* It consists of round or square plates of copper and zinc, commonly from 1 to 4 inches across. The pile is formed by placing them one on the other, a zinc and a copper plate being soldered together throughout. Care is to be taken that all the copper plates are underneath, and all the zinc uppermost, or *vice versâ.* Between each pair of plates insert a piece of flannel or pasteboard, saturated with the liquid *l*, which is generally either dilute sulphuric acid, or a solution of common salt; and the elements of the galvanic circuit will stand in the following order, beginning from the bottom of the pile Z C *l* Z C *l* Z C *l*, &c. When from 30 to 50 pairs of plates have been thus arranged, the flannel soaked in the liquid will be subjected to such a pressure, that a great portion of the liquid will run down. If, therefore, the number of plates is considerable, say 100 or more, it would be better to make two piles of 50 pairs each, near together, but in inverse order, and connect either the undermost or the top plates by means of a strip of copper. In this arrangement, the outermost zinc and the outermost copper plate may be dispensed with, as they are not in contact with the liquid, and the last copper plate will have a positive electrical tension, and the last zinc plate a negative tension, just the same as in the single battery.— The electromotive power in such piles is increased by amalgamating the zinc plates; in which case the sulphuric acid may advantageously be diluted with from 20 to 30 times its amount of water. Muncke asserts that its power may be increased from two to four fold, by covering the pasteboard, which is to be soaked in the liquid on one side, with powdered black-lead, and laying that side next the copper. The electromotive power may also be increased by substituting some more negative metal, as silver for the copper; and according to Bunsen, the maximum effect is gained by making the pile of amalgamated zinc and copper plates, and using Warrington's chromic acid liquid, described a little higher up. Bunsen says, that from a cylinder of fine carbon (for its preparation, see the preceding section), 7 inches long, 100 slices may be cut, which will not require cleaning like the copper discs, as they need only to be kept in the liquid when not in use.

Compound batteries may in like manner be formed of Wollaston's trough apparatus, Oersted's trough or Hare's spiral batteries, merely observing to place the individual members of it in the same order, and then connecting them by means of copper wires. The whole is to be immersed in the liquid, either in a trough of sufficient size to contain it, or the liquid must be poured into the separate copper or glass cylinders.

Faraday's trough apparatus, improved by Young, will be found very convenient for readily constructing an efficient pile of many plates. The copper and amalgamated zinc plates, presenting a surface of about 4 square inches each, are to be ranged alternately in a wooden frame. Every two copper and zinc plates are connected by a strip of metal, as is shown in *fig.* 185. When several such pairs are combined in a battery they are put together, so that one copper plate stands between two connected zinc plates, and one zinc plate between two copper ones, the distance between each being one line. This combination is represented in the annexed diagram, C standing for the copper, Z for the zinc, and ⌒ for the metallic connection: —

Fig. 185.




C Z C Z C Z C Z C Z C Z C Z C Z

After the plates have been thus arranged, plunge them into a trough of convenient size, of either wood, earthenware, or japanned ware, containing either sulphuric acid diluted with from twenty to thirty times the quantity of water, or Faraday's liquid, the composition of which we have given above. When the operation of the battery is to be discontinued, you have only to lift out the plates by the common frame in which they all stand.

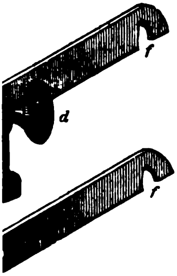
The following batteries of this class merit a brief notice on account both of their magnitude and their remarkable performances. The great battery of the Royal Institution in London consisted of 2000 pairs of plates, each of which had an effective surface of twenty-two square inches; it was with this apparatus that Sir H. Davy made the important discovery of the compound nature of alkalis, and the practicability of their being decomposed. Next to this we may mention Children's great plate battery, which consisted of 16 pairs of plates, combined on Wollaston's principle, each plate being 6 feet long by 2⅔ feet wide, so that the effective copper surface of each was 32 square feet, and when these were connected in *one* the entire surface amounted to 512 square feet. Hare's deflagrator or calorimotor was combined of 80 zinc and copper spirals, the zinc surface containing 54 square inches, and the copper 80 square inches. Stratingh's deflagrator consisted of 100 pairs arranged on Wollaston's principle, each zinc surface presenting 200 square inches; it could be used either as a pile of 100 pieces, or as a single battery of 40,000 square inches of zinc (or 277 square feet of zinc, and 544 of copper).

All these single-fluid batteries have, however, fallen into disuse, except when powerful physiological effects (§ 515.) are to be produced, since the discovery of the great efficacy of batteries with two liquids, which with a smaller number of pieces varying from 2 to 40, of average dimensions, (having an effective surface of from 20 to 100 square inches,) exert a power equal to that of the gigantic battery belonging to the Royal Institution.

These batteries are made by combining either Daniell's, Grove's, or Bunsen's single batteries, arranging the individual members of the compound battery near to one another, and connecting the heterogeneous electromotors on the principle of a voltaic pile by strips or wires of copper. It is convenient to divide the number of component members into two equal factors, that they may be easily arranged in a rectangular space. The Grove's battery, constructed by Jacobi of Petersburg, contains 64 platinum plates, each of 36 square inches surface, so that their combined surface amounts to 16 square feet. Probably this is the most powerful battery ever made, not excepting even that of the Royal Institution; for, according to Jacobi's comparative estimate (see the preceding paragraph), its effect is equal to a Daniell's battery of 266 square feet, or a Hare's battery of nearly 5500 square feet.

It is of essential importance in all compound batteries not to waste the electromotive power, and to ensure their utmost efficiency, that a perfect metallic contact should be established between the parts by means of short and good conductors. Copper wire, or strips of copper of suitable thickness, are the best conductors; if they are not immediately fastened to the heterogeneous metals, as in Wollaston's and Young's batteries, small cups may be soldered on to the metal plates, these cups filled with mercury, and the ends of the connecting wires immersed in this liquid metal. Or the many inconveniences attending the use of quicksilver may be obviated by the use of copper binding screws. In this case care must be taken that the contact of the metals is perfect. This will be best secured by electro-gilding (§ 519.) the points of the contact, which may be done at a small expense and with little trouble. A screw ap of the kind referred to are represented in *fig.* 186. *a* is a strip of metal bent at right angles, and soldered on to each of the electromotors; on it stands an upright piece of metal *b*, turning on an axis or screw. In this upright a hole is drilled to receive the nut *d*, by which the strip of metal *c* is secured to *b*. A notch is made at *f*, in this last-named little bar, by which it may be fastened to the next piece of the battery by its connecting screw. All these pieces of apparatus should be of copper or brass; and for

Fig. 186.



lready given, it is advisable to gild, silver, or plati-
n by the volta-typing process.

§ 507.

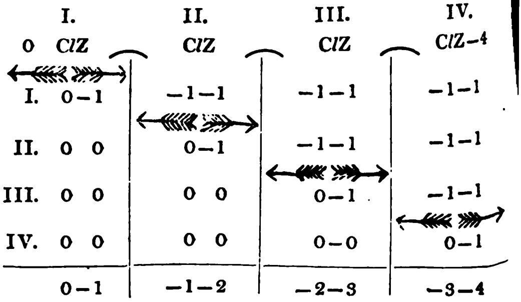
of the batteries we have just been describing there
iar induction of the tension, excited by the contact
motors with the intermediate fluid. The + and –
licited in the respective metals, are urged in op-
ns to the sides on which the similar electromotors are
nnecting wires and the intermediate liquids acting
s. The dissimilar electricities are accordingly
in the two extreme electromotors of the circuit,
ce called *poles*; that being termed the *positive pole*
n the + electricity tends, and the other the *negative*
which the – electricity moves.

the arrangement of a common voltaic battery (see
ding paragraph), its poles consist of a pair of zinc
er plates, and as the outermost plate of the + pole
d that of the – pole is copper, the + pole has some-
n called the *zinc pole*, and the – the *copper pole*.

g to the construction described in the preceding
e last member of the circuit, the copper for instance,
with the earth, its state of positive electrical tension
, and it will acquire 0 electricity. The electrical
other electromotor of the voltaic pile communi-
tension by means of the conducting wire to all
mbers of the circuit. The like happens to the
fourth, &c. members of the whole battery; whence,

consequently, the electricity is carried off from all the electromotors of the same name (in the case supposed from the copper plates), which lie on the side that is in contact with the ground. The electricity of the other electromotors, i. e. of the zinc plates, will be the sum of that of the successive pieces; thus the intensity of the —electricity towards the opposite pole increases in arithmetical progression, so that in the *n*th plate of the battery, the tension would be *n* times greater than in the first. The same ratio obtains with regard to the + electricity, if the outermost zinc plate be connected with the ground. Biot, who has performed a number of exact experiments to ascertain this point, found the electrical tension in such batteries was altogether independent of the magnitude of the effective areas of the electromotors; so that, if the electromotive combination of two batteries be alike, and they consist of the same number of plates, the intensities of their tensions will be equal, even though the electromotors of one battery be 100 times larger than those of the other.

The annexed diagram will perhaps render more easily intelligible the increasing tension and induction of the electricity in compound batteries. C expresses the copper which is in a state of positive, and Z the zinc, which is in a state of negative tension; *l* is the exciting liquid for the two metals; ⌒ the connecting wire between them; and the ⟶ marks the direction taken by the + and — electricities in the circuit; the intensity of the tension in each single battery is assumed = 1, and the extreme copper plate is supposed to be connected with the ground.



If the zinc plate be connected with the ground instead of the copper one, we shall have a similar scheme, with this difference only, that the tension increasing through the successive nembers of the battery will be positive: the scheme can f course be carried to any number of terms at pleasure.

xt, we will suppose both the ends or poles of the battery to ulated; we will further assume its electromotors to be copnd zinc, that the former is on the right and the latter on ft hand; then it follows that the + electricity of the copper through all the plates in the circuit to the left hand, and electricity of the zinc to the right. Hence there proceeds the middle a progressive accumulation of + electricity ds the left hand, and a similar accumulation of — electricity ds the right; so that the two extreme plates exhibit an sed intensity of tension, whilst in the centre it ceases altor, the centre being, in fact, its point of indifference. Rethe connecting wire from any two members of the series, ou obtain two batteries, in which the same electromotive tion is found to exist as has been just described: disconnect nd wire and the like occurs again.

The following diagram will perhaps render the above nore easy to comprehend; the same signification is to be ttached to the symbols as in the former scheme. Assume he tension between the copper and the zinc = 1, then, if ach is perfectly insulated, the difference of their tensions vill remain the same, that of the copper being + ½, and that f the zinc — ½.

Diagram of a Battery of Three Pairs of Plates.

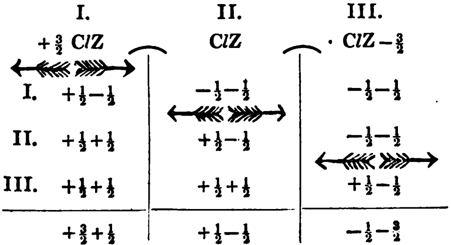
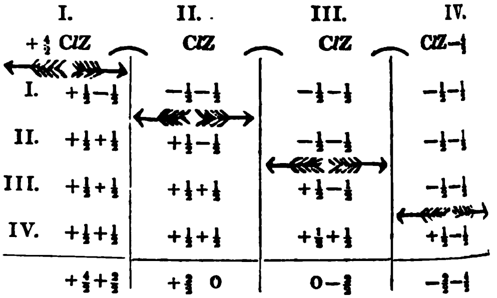
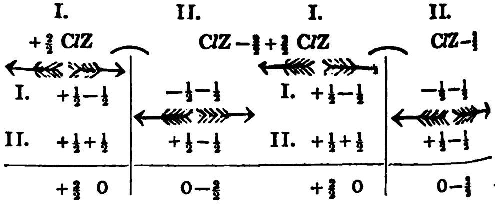

I.
II.
III.
+ $\frac{3}{2}$ C/Z
C/Z
C/Z − $\frac{3}{2}$
I. $+\frac{1}{2}-\frac{1}{2}$
II. $+\frac{1}{2}+\frac{1}{2}$
III. $+\frac{1}{2}+\frac{1}{2}$
$+\frac{3}{2}+\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
$+\frac{1}{2}-\frac{1}{2}$
$+\frac{1}{2}+\frac{1}{2}$
$+\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{1}{2}$
$+\frac{1}{2}-\frac{1}{2}$
$-\frac{1}{2}-\frac{3}{2}$

Diagram of a Battery of Four Pairs of Plates.



	I.	II.	III.	IV.
	$+\frac{4}{2}$ ClZ	ClZ	ClZ	ClZ $-\frac{4}{2}$
I.	$+\frac{1}{2}-\frac{1}{2}$	$-\frac{1}{2}-\frac{1}{2}$	$-\frac{1}{2}-\frac{1}{2}$	$-\frac{1}{2}-\frac{1}{2}$
II.	$+\frac{1}{2}+\frac{1}{2}$	$+\frac{1}{2}-\frac{1}{2}$	$-\frac{1}{2}-\frac{1}{2}$	$-\frac{1}{2}-\frac{1}{2}$
III.	$+\frac{1}{2}+\frac{1}{2}$	$+\frac{1}{2}+\frac{1}{2}$	$+\frac{1}{2}-\frac{1}{2}$	$-\frac{1}{2}-\frac{1}{2}$
IV.	$+\frac{1}{2}+\frac{1}{2}$	$+\frac{1}{2}+\frac{1}{2}$	$+\frac{1}{2}+\frac{1}{2}$	$+\frac{1}{2}-\frac{1}{2}$
	$+\frac{4}{2}+\frac{2}{2}$	$+\frac{2}{2}$ 0	0 $-\frac{2}{2}$	$-\frac{2}{2}-\frac{4}{2}$

Subdivision of a Battery of Four Pairs of Plates into Two of Two Pairs each.



	I.	II.		I.	II.
	$+\frac{2}{2}$ ClZ	ClZ $-\frac{2}{2}$		$+\frac{2}{2}$ ClZ	ClZ $-\frac{2}{2}$
I.	$+\frac{1}{2}-\frac{1}{2}$	$-\frac{1}{2}-\frac{1}{2}$	I.	$+\frac{1}{2}-\frac{1}{2}$	$-\frac{1}{2}-\frac{1}{2}$
II.	$+\frac{1}{2}+\frac{1}{2}$	$+\frac{1}{2}-\frac{1}{2}$	II.	$+\frac{1}{2}+\frac{1}{2}$	$+\frac{1}{2}-\frac{1}{2}$
	$+\frac{2}{2}$ 0	0 $-\frac{2}{2}$		$+\frac{2}{2}$ 0	0 $-\frac{2}{2}$

Electroscopic observations will at once prove the existence of these particular states of tension in the different batteries; if, however, the electroscopes or electrometers used are not sufficiently delicate to indicate the tension, we must call in the aid of a condenser, by means of which the feeblest degree of tension will be rendered visible.

Compare a pile both whose poles are insulated with another, one of whose poles is connected with the ground, and the following differences will be observable: — That which is not insulated shows throughout its whole extent only + or only — electricity, the other has 0 electricity at the pole in connection with the ground, from which to the other pole the intensity of the tension continually increases. In the battery whose poles are insulated, both species of electricity are found proceeding from the centre or point of indifference, so that one half contains only + and the other only — electricity, increasing equally in intensity *towards* each pole; however, the intensity at each pole of that ery, which was insulated at both ends, is only half that of the lated pole of the second battery, which had its other pole ected with the earth.

he insulated piles in this respect present a striking analogy to polarity of a bar magnet, in one half of which in like manner ectricity resides, and — electricity in the other half; in the dle, between the two poles, is the point of magnetic quiescence, electricity; and if the bar be divided, each of the fragments ires a similar polarity. (§ 436.)

§ 508.

esides the electrical piles already described there are some rs in which the elements composing the individual members he battery are somewhat differently combined, viz. the *dry* , *piles of two elements only*, and *secondary piles*.

he first, called also after their inventor, *Zamboni's piles*, differ the common hydro-electric batteries principally in this, that presence of the electromotive liquid is dispensed with in them, that in its place is substituted some moist substance of low lucting power, generally paper. The electromotors in these s are composed for the most part of Dutch gold (copper) and r (zinc) paper pressed one on the other, with their paper sides ther, out of which discs are cut with a diameter of from an inch to an inch. More powerful pairs of plates may be ined by using only the silver paper and smearing its paper with a thin coat of honey, on which some finely pulverized oxide of manganese has been sprinkled, and all the sides simiy coated are presented one way. Powerful pairs of plates also be made by pasting pure gold leaf on the paper side of -paper. These plates are then to be arranged, just as in the inary voltaic pile, one above the other, so that the similar tallic surfaces may all lie one way; press them tightly toher; tie them with pretty stout silk threads, and press them a glass tube of convenient size. The metal rims of the tubes, ich must be well connected with the outermost pairs of plates, n the poles of the pile, the negative pole being in the extreme surface, and the positive in the extreme copper or manganese face.

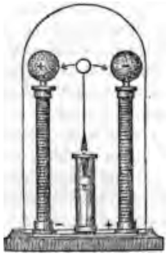
The electromotive energy called into action in these dry piles ess than that excited in the moist or hydro-electric piles, prinally on account of the imperfect conduction of the paper. The umulation of electricity at their poles also goes on less rapidly, consequently the electrical tension continues for a long while ltered; whereas, in all moist piles, even in the most constant them, the tension is maintained, comparatively speaking, for a short time, on account of the chemical action and decom-

position of the electromotive fluid — causes of disturbanc
do not exist in the dry pile. To render the electrical te
a Zamboni's pile immediately perceptible on an elec
without condensation, the pile must consist of at least f
to 1000 pairs of plates.

Behrens, Deluc, Biot, Jäger, Ritter, Kämtz, ar
have at different times employed various material
construction of similar dry piles, but none have be
to be equal in power to those made of zinc-paper a
ganese. Watkins, of London, made a remarkabl
only one metal, and without any intermediate cc
It consisted of from 60 to 80 zinc plates, about
inches in size, purely metallic on one side, but on
covered with the ordinary film of oxide. These pl
so arranged in a wooden trough, that all the clear
surfaces stood one way, and between each pair of pl
was an extremely fine stratum of air, as they we
immediate contact. In this apparatus the two zin
acted as the two different metals do in other piles
film of damp air performed the part of the paper.

The length of time during which the tension of tl
lasted led to the construction of a kind of *electrical per*
tion. It is formed by placing two Zamboni's piles (*fig.* 1
containing at least 1000 pairs of p
vertical position within 1½ inch or
of each other, so that their dissim
may be opposite both at top an
The lower poles are then conn
means of a strip of copper, but
terminate in two metal knobs.
tween these two polar balls, pla
pendulum, just balanced above its
gravity. The pendulum rod sh
glass or gum-lac, and on its top it
a small ring or ball of gold or sil
on coming in contact with one of
of the battery is impregnated wit
tricity. It is then repelled, b
similarly electrified. The other pole attracts it, electri
then repels it, and thus this oscillating movement is n
without cessation. As the action of these piles is, aft
impaired by external causes, the expectation has not bee
that they would supply a perpetual motion.

Fig. 187.



Bohnenberger's electroscope, improved as it has sinc
Becquerel and Fechner, is an apparatus of far greater u
that we have just described. It acts on the principle c
manent tension in a Zamboni's pile. We have alread

l this extremely delicate instrument (*fig.* 157.), and have out its application. The action of the small dry pile on roscopic gold leaves, vibrating between its two poles, will :tly understood from what has just been advanced.

iles of two elements only, likewise an invention of Zam- ınsist of one metal and one intermediate conductor, ry or moist; if the former, the discs are of silver paper, ı all their metal sides one way; if the latter, a number of f tinfoil of some such shape as this ◊, are laid in two lasses which contain water, in such a manner that the half lies in one glass, and the broad end in the other. me time these piles acquire at their poles a feeble elec- ısion, which they will maintain for several days, the metal ıibiting + electricity in the dry pile, and the pointed end nc being + electrified in the moist one.

econdary piles, sometimes also called *Ritter's* piles, consist ıate layers of homogeneous metal plates, between which .oist conducting substance is interposed. When they one no electromotive tension is excited; but after they en for some time connected with the poles of a voltaic if they be disconnected from it, the end which was joined ositive pole of the battery will have become + electrified, which was connected with the negative pole will be — :d. A similar effect may be produced in silver, gold, and ı wires, if of sufficient thickness, by connecting their :rnately, the one with the + and the other with the — a powerful battery, and maintaining this connection for ı hour. The charge is only transient in its duration, ;es off the more quickly the fuller the tension in the first . Various attempts have been made to explain this ɜnon, which seems most probably connected with some ıg influence.

'oltaic Piles in an Electro-statical and Electro-dynamical Condition.

§ 509.

simple and compound voltaic batteries, in the condition 'e have considered as yet, display their electromotive ac- ɔlely by the *electropolar tension* of their elements, the ıotors being excited by contact with the intermediate ır with some dry conductor The intensity of this tension, :d with that produced by friction, even in batteries con- ıf a great number of plates, is extremely weak, as electro- bservations prove.

This is sometimes called the *electrostatic* condition, which may be converted into the *electrodynamic* by connecting the two electromotors of a single, or the two poles of a compound, battery together, by means of any good conductor. The ± electricities rendered sensible are set in motion, and a current is generated the same as in frictional electricity, in which the ± electricities combining produce 0 electricity. The connections may be variously formed, the main point being that they be of good conducting materials (§ 469.), however shaped or combined, as substances of low conducting power would not transmit the current. The connection is established in the most simple manner possible, by placing those parts of the electromotors which are not immersed in the liquid together, or else they may be joined by a wire or strip of metal. Other conducting bodies may form parts of the circuit, as *ex. gr.*, a fluid, a living animal, or vegetable, &c. Outside the simple voltaic arrangement, the current goes from the negative metal, as being the electromotor which is in a state of positive tension. Outside the compound battery it runs from the + pole through the connecting arc to the negatively excited electromotor; that is to say, to the positive metal, or to the − pole, whereas, within the battery itself the current runs in exactly the opposite direction; that is to say, in a single voltaic arrangement from the positive metal through the electromotive fluid to the negative metal, and in a battery from the negative pole through all the intervening pairs to the positive pole. In the single batteries represented in *figs.* 175—177, the direction of the current is marked by arrows. In this case, by the current, is to be understood only the positive one; the negative current arises simultaneously with it, and runs in an opposite direction. (§ 488.)

§ 510.

Faraday has adduced a variety of proofs to establish the identity between electricity excited by contact and by friction; the important distinction between them is, that in the former, the exciting cause is constant, and by consequence the effect is so too, but in friction electricity this is not the case. The conductor of an electrical machine when charged, as we have already seen, loses its electrical tension immediately on a connection being established by a good conductor between it and the ground, and we can only obtain an approximation to a constant stream in a good conductor by connecting it, while the machine is in action, with the prime conductor and cushion. An electrical battery shows the same defect, for, when it is discharged, the current sent through the conductor is instantaneous, and to renew the effect the bat-

must be recharged. In a voltaic battery, on the contrary,
xciting cause is permanently at work ; hence, after connection
tablished with the ground, its electrical tension is excited and
tained, and when the circuit is completed, the stream is
ted uninterruptedly so long as the circuit is not broken, and
ng as no change takes place in the electromotive powers of
lectromotors and their intermediate liquid ; because, so long as
± electricities in the interior of the battery neutralize each
r by the current, the condition is re-established on which a
electromotive excitation depends. Again, there is a differ-
in the effects of voltaic and friction electricity, owing to the
tity and intensity of the electricity developed by each of
e modes respectively. By friction, a current is obtained of
t intensity, but containing a small quantity of the electric
l ; by voltaism, generally speaking, a much larger quantity is
loped, but always of a low degree of tension : hence the
est electrical battery may be charged, by means of a voltaic
instantly to the degree of tension shown by the latter at its
s, by connecting the two together by means of wires. A still
e decisive proof of the difference as to the quantities of elec-
ty obtained from these two sources is afforded by an experi-
t of Faraday's, which will be explained below. (§ 512.) In
equence of this difference, all those operations which depend
cipally on the intensity of the electric fluid are more feeble in
voltaic than in the ordinary electric current, while such as
dependent on its quantity and duration are stronger than
e of the latter. The above remarks must be understood to
r exclusively to hydro-electric batteries, as the current emitted
the dry piles is extremely feeble.

§ 511.

t now remains that we should describe and explain the dif-
nt effects exerted by a hydro-electric current in its passage
ugh different bodies. To do this properly, and to judge
ectly of its influence, we must first learn on what the absolute
e of a current particularly depends, and by what causes this
e may be modified. Accurate conclusions as to these matters
only been arrived at within comparatively a few years, to
ch conclusions we have been conducted in part by the shrewd
retical deductions of Ohm, and the careful observations of
hner and others.

n all investigations of this kind, it is requisite that we should
e an accurate measure of the intensity of the current, in order
arn the influence exerted on it by the varied combinations of
batteries, and the changes which arise in its intensity. The
rent effects which the current produces furnish us with such

a measure; they are not, however, all equally well adar this purpose; we shall presently (§ 522.) show which ar preferred, and how they are to be applied.

There are two factors which especially determine the intensity of the current, and on whose variations the inte the effects produced regularly depends. One of these, also the proximate or exciting cause of the electric cu the *electromotive force* itself; and the other, or modifyin is the *resistance to its conduction.*

The electromotive force depends on the *quantity* or electricity set in motion. In simple voltaic arrangem quantity of electricity expresses the difference of the ten tween the two electromotors; it depends both on the m which they are combined (§ 505.), and also on the extent surfaces in contact with the intermediate fluid. In a co battery the whole force will be proportional to the su electromotive forces of the individual pairs composing it.

The *retarding force* is compounded of the different which impede the progress of the current; it forms th by which its effect is more or less impaired. These arise in part from the *imperfect conducting power* of th completing the circuit, and in part from the *resistance* w current encounters every time it passes from one cond another.

The *conducting power* of a body, or its capacity for tra electricity, varies with its material structure: that of th is some millions of times superior to that of the best co liquids, with which they have been compared.

The conducting powers of the metals, ascert various ways, are as follow: — According to

Becquerel.		Ohm.		Davy.	
Copper	= 100	Copper	= 100	Silver	=
Gold	= 93·6	Gold	= 57·4	Copper	=
Silver	= 73·6	Silver	= 35·6	Gold	=
Zinc	= 28·5	Zinc	= 33·3	Lead	=
Platinum	= 16·4	Brass	= 28·0	Platinum	=
Iron	= 15·8	Iron	= 17·4	Palladium	=
Tin	= 15·5	Platinum	= 17·1	Iron	=
Lead	= 8·3	Tin	= 16·8		
Mercury	= 3·45	Lead	= 9·7		
Potassium	= 1·33				

Lenz.		Reiss.		Pouillet.	
At 32° Fahr.					
Silver	= 136·25	Silver	= 148·74	Gold	= 103·5
Copper	= 100	Copper	= 100	Copper	= 100
Gold	= 79·79	Gold	= 88·87	Platinum	= 22·5
Tin	= 30·84	Cadmium	= 38·35	Brass	= 15·2
Brass	= 29·33	Brass	= 27·70		= 23·4
Iron	= 17·74	Palladium	= 18·18	Cast steel	= 13·0
Lead	= 14·62	Iron	= 17·66		= 20·8
Platinum	= 14·16	Platinum	= 15·52	Iron	= 15·6
		Tin	= 14·70		= 18·2
		Nickel	= 13·15	Mercury	= 2·6
		Lead	= 10 32		

The above numbers express the relative lengths of the wires which, with equal diameters, conduct the same quantity of electricity.

'he conducting power is not always uniform, it varies accord- to the temperature and the force of the current: Lenz's ›riments on this subject prove that the conducting power of als decreases when their temperature is raised, that the rate his decrease varies in different metals, and that in all it is ined within certain limits: with regard to liquids, Mariani shown that their conducting power is increased by raising r temperature. The current of electricity itself, as we shall presently, is the principal cause of the conducting bodies' 'ease of temperature; it acts variously, according to the ıre of the liquids employed, chemically decomposing them it passes through them, and thereby, in a short time, fre- ntly impairing their conducting power to a great extent.

t is self-evident, that the better conducting power any sub- ıce possesses, the less will be the resistance to be overcome by current in its transmission through such a body. The ›unt of this resistance depends not merely on the structure of conductor, but also on its length, thickness, and temperature. nce, that portion of the resistance in each body really owing ts material structure, can be ascertained only by giving equal ;ths, breadths, and temperatures to the bodies compared ether. Fechner, from experiments which he performed, with accuracy and ingenuity for which he is distinguished, dis- ered the following laws:

'he resistance offered by the metallic portions of the pile or *ery*, is directly as their lengths, inversely as their transverse ions, (in wires, as their diameters squared,) and inversely as their conducting power, which is, however, influenced by ir temperature. By length, is to be understood their dimen- ıs in the direction in which the current travels.

'he resistance of the liquid conductor is proportional to the dis- e of the electromotors from each other in the liquid, inversely he extent of the metallic surface acted on by the liquid, in-

versely also as the conducting power of the latt ever, is affected by the temperature.

> Let l be the length of the metallic co thickness of the stratum of liquid betwe motors; t the transverse section, or area acted on; c the conducting power; and I which may be expressed by the following fo
>
> $$R = \frac{l}{t.\,c}$$

Besides the resistance to conduction of the me parts of the battery, the current has further t *resistance to transmission* each time it passes out c solid body, whether it be an electromotor or me of electricity, and *vice versâ*. In this we have a to the vibrations of sound, light, and heat, wl retarded by passing out of one medium into ano idea be correct, which some have entertained phenomena are caused by certain undulations ir resistance offered to the current might be explair manner as the retarded undulations spoken of a first noticed this resistance, the existence of causes by which it was affected, he proved by a v ments. Poggendorf also performed numerous which he was led to the following conclusions.

The resistance to be overcome by the curren from the solid to the liquid, and *vice versâ*, deper duction of the electric fluid in the interior of varies, consequently, according to the nature of that of the metal in contact with it, being very by the character of the surface of the latter. Th the electric current the stronger the resistanc where it quits one conductor for the other. If t traversed be changed, but the intensity of the the same, then the resistance varies in a ratio ratl inverse ratio of the increase in the surface. If t be raised it is diminished, and in the passage of t one metal to another it is indefinitely small.

To estimate the resistance to conduction in a b be acquainted with the resistance of some one body, such as a wire of known material, length temperature; the resistance such a wire actually it would offer if it formed a part of the battery, w unit of measurement. This resistance is estimat the results effected by the action of the current, a as a unit for comparing similar actions. Hence t the conduction of the current offered either by a or by any particular part of the battery, may b ome multiple, or some fraction of this unit; or, what is the same hing, we may find what equivalent length of wire will make the me resistance. Ohm called the resistance referred to such a it *the reduced length*, and a body or a part of a battery of *n* nes the reduced length is equal to another whose resistance t duction is *n* times that of the wire, which is considered as the t.

If now we have a number of wires of various metals, and of the same thickness as the normal wire, their lengths must be respectively as their conducting powers, in order that heir resistance to the transmission of the electric current may e the same as that of the normal wire; if this proportion be bserved, we may substitute one of these wires for another connect the battery, and in each case the resistance will be qual; if the wires be of the same metal, but of unequal ickness, this resistance diminishes as the squares of their ameters. Suppose, now, the unit of measurement is a pper wire 10 inches in length, then adopting the values iven by Riess, an equal resistance would be offered by iron wire of the same thickness and 1¾ inches in length, or y a platinum wire 1½ inches long, or by a leaden wire $\frac{3}{100}$ inches, or by a silver wire 15 inches long: each of hese wires may be n^2 times longer, if it be *n* times thicker, ithout its resistance to conduction being increased. In ike manner we may determine the magnitude of the retarding force of any other conductor whatever, by means of which we establish the connection of the battery. Suppose, now, we wished to know what must be the length of a copper wire that would offer a resistance to the conduction of the electric current equal to that of the human body, we must first find what length of wire would equal the reduced length of the human body. In order to determine the ratio between the resistance of any single member of the pile to the human body, we have only to substitute the one for the other, and thence determine the equivalent length of wire, which, multiplied by the number of pairs of plates in the battery, will give the reduced length of the whole battery, and it will always be found that its resistance to conduction is much less than that of the human body.

Since, therefore, the conducting power of a body is intimately connected with the resistance a current of electricity has to overcome, the force of the current must always exceed this retarding influence, or motion will not ensue; hence it is apparent why certain substances may act as conductors to a powerful current which are non-conductors to a feeble current, their conducting power becoming an indefinitely small magnitude when the current is weak.

Now, with regard to the entire resistance which impedes the action of a battery, it is made up of two parts, viz. out of that resistance which the current meets with in its passage through the battery and that which is offered to it in the connecting wires exterior to the battery itself. The retarding force in the battery is equal to the sum of the retarding forces of the different pairs of which it is composed; it results, therefore, from the resistance to conduction offered by the stratum of fluid between the electromotors, from the resistance to the transmission of the current from the solid to the liquid and from the liquid to the solid, and from the retarding influence of the metal connecting contiguous plates. Hence it follows that in a similar combination of compound batteries the resistance will be proportioned to the number of plates. The retarding force of the connecting wires necessarily depends on the material of which they are made and on the mode of their combination; as a general rule, it is increased in proportion to the length and thinness of the wires and the lowness of their conducting power. It is especially aggravated by the interposition of bad conductors in the circuit, such as liquids or the human body, as by this means there is the further impediment caused by the current's passing out of one medium into another. This is, for the most part, that portion of the electric circuit on which the action of the whole battery is brought to bear in the performance of experiments; any change in it must necessarily affect the total resistance of the battery.

If now our object be to determine the influence of an electric current on the electromotive force, which is especially the active factor in exciting and maintaining the current, we shall find the following law of Ohm's important, as being applicable under all circumstances, and as referring to all the causes which tend to impede the action of the battery; it is, that *the intensity of an electric current, when a battery is in action, is directly as the whole electromotive force in operation, and inversely as the sum of all the impediments to conduction.* It may therefore be expressed by a fraction whose numerator is the electromotive force, and its denominator the sum of the resistance of all its parts. Let I be the intensity of the current, E the whole effective electromotive force in the battery, R its constant retarding influence, and r the variable retarding influence in the connecting wires; then

$$I = \frac{E}{R + r}.$$

By means of Ohm's fundamental law, which admits in its applications of the most varied developments, the first clear insight has been afforded into the apparently intricate circumstances which affect the performances of electrical batteries.

If, according to Ohm's formula, we put the intensity of the current in a simple voltaic arrangement whose excited surface is 1,

$$\text{I.} \quad I = \frac{E}{R + r};$$

then the intensity of a current from a battery of n pairs of plates will be

$$\text{II.} \quad I' = \frac{n\,E}{n\,R + r};$$

and in a single voltaic arrangement whose surface is n times greater than 1, the resistance to conduction being diminished inversely as the area of its transverse section, the intensity becomes

$$\text{III.} \quad I'' = \frac{E}{\frac{R}{n} + r} = \frac{n\,E}{R + n\,r}.$$

Now, if the action increases or diminishes in any part of the battery, either by an increase in the electromotive force (E), or by a decrease at any point in the retarding influences ($R + r$), the action of the battery will undergo a corresponding increase or decrease throughout, *i. e.* the increase or decrease of the intensity caused by a variation in the electromotive or retarding influences, is equally distributed throughout the battery. As, further, the effect of the current depends on the quantity of electricity circulating in the current, the amount of electricity flowing through every section of the battery will be equal, whatever its area or the material of which it consists. Wherever the space is narrowed through which the current flows, the mass of electricity must be more condensed, whereas in a larger section it becomes proportionally rare; in both cases the quantity transmitted is equal. The area of the section through which it passes will therefore regulate the *intensity* of the current, *which in every part of the electric circuit will be inversely as the transverse section of the conductor through which it passes*, *i. e.* it increases in proportion as the area through which it is transmitted is diminished. This variation in the *intensity* of the electricity whilst the *quantity* remains unaltered, is the cause of many of the phenomena of the voltaic current. The reader must not confound the *intensity of the current* in a battery at work with the *intensity of the polar tension* in an insulated battery; for the latter depends on the quantity of electricity liberated by its antagonist; it is measured by the repulsion of the particles of the dissimilar fluids, and is determined by its influence on an electrometer; whereas the intensity of a current of electricity depends on the quantity of the ± electricities which neutralize each other at every point of the circuit continually. The *total intensity* of the current will consequently be proportional to the quantity of electricity passing through every portion of the circuit, whilst its *relative intensity* will depend on the manner in which the quantity of fluid at each particular portion of the circuit exerts its influence.

From a consideration of the above, and especially from the explanation given of Ohm's law, as to the intensity of the current in a voltaic battery, we may draw the following inferences as to its action: —

1.) When the resistance to conduction offered by the connecting wires is very small, compared with that in the battery itself, the battery does not act with more power than each single pair of plates composing it; but a single voltaic arrangement acts the more powerfully the greater the excited surfaces of its electromotors.

If the resistance to conduction, r, in the connecting wires, be very small, compared with that, R, in the whole battery, it may be disregarded, and the values of the intensities, I, I′, I″, in the preceding formulæ, become

$$I = \frac{E}{R};\ I' = \frac{n\,E}{n\,R};\ I'' = \frac{n\,E}{R},$$

or they are as

$$I : I' : I'' = E : E : n\,E.$$

2.) Now in the converse case, that is, when the resistance to conduction in the connecting wire or other body is very great, as compared with that of the battery itself, then the action of the battery is more powerful, according to the number of pairs of plates composing it; but a larger pair does not act with perceptibly more force than a small one.

In this case let R, the resistance of the whole battery to the conduction of the current, be indefinitely small as compared with r, that of the connecting arc; then, neglecting R in the preceding formulæ, we have for the intensities I, I′, I″ of the currents, the following values: —

$$I = \frac{E}{r};\ I' = \frac{n\,E}{r};\ I'' = \frac{n\,E}{n\,r}$$

or they are to each other as

$$I : I' : I'' = E : n\,E : E.$$

.) Since the resistance to be overcome by a compound hydro- tric battery, at any point of its circuit, affects its efficacy, we l secure the maximum effect from a current in a battery of n surface, by making the resistance in the battery equal to : which the current has to surmount in the connecting wires.

.) But since, in the construction of a battery, many causes are peration by which the electromotive force may be influenced, ı as the polarization of the metals (§ 504.), the chemical nge produced in their surfaces, or in the intermediate liquids, ollows that a permanent and almost unvarying effect in the rent can be attained only in those batteries where these disturb- causes exist in but a low degree, or where their forces para- : each other. See § 518.

rom the whole, then, it follows that the efficiency of all vol- batteries depends entirely on quantitative differences, and t the same force, I, is to be maintained whatever change may nade in either term of the formula $I = \frac{E}{R + r}$, by which Ohm's is expressed.

D. *Different Effects of the Hydro-electric Current.*

§ 512.

The effects produced by a hydro-electric current may be ar- ged under the following principal classes: 1.) *Magnetic*, 2.) *minous*, 3.) *Thermal*, 4.) *Physiological*, and 5.) *Chemical nomena*, which we shall proceed to consider in the order in ich they have been enumerated.

l.) *Magnetic Phenomena.* These are the last observed, not ing been noticed until 1820. One of the most important of m we shall consider before speaking of any of the other effects duced by the electric current, because its discovery has fur- hed us with the readiest means of becoming acquainted with atever is essential to be known concerning these currents. is phenomenon is the influence exerted by a stream of electri- y on a magnetic needle, which, under its influence, acts both an electroscope and an electrometer; hitherto we have con- ered these instruments merely as affected by electricity in a te of tension.

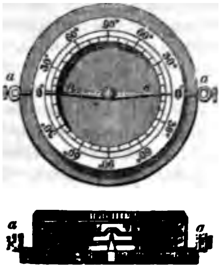
Every variation needle (§ 442.) placed near to a permanent elec- c current is deflected from its polar position, more or less, so that en the stream of electricity is transmitted from south to north low the needle, its north pole is turned eastward or towards the right hand, but when the current runs from north to south, th north pole of the needle deviates to the left hand or westward these circumstances are exactly reversed when the fluid is mad to go in the same directions above the needle. Currents of electricity sent simultaneously in opposite directions above and belo a needle, deflect it still more powerfully. If the current b powerful, it is sufficient to carry it but once over or under common needle in order to deflect it, but if the electric stream b weak, it must be conducted several times round the needle, thu repeating or multiplying the deflecting influence of the singl current; if the current be extremely feeble, it may perhaps b requisite to use an astatic double needle (*fig.* 139.), in whic the lower needle will stand between, while the upper one is abov the currents, so that both directions of the stream tend to defle the needle the same way. *Jacobi's Compass Galvanometer* (a) act on the first principle, the *Multiplier* (b) invented simultaneousl by *Schweigger* and *Poggendorf*, on the second, and *Nobili's Doub Galvanometer* (c), on the third. The instruments just named ar not equally applicable for all kinds of currents: the use of one o the other is regulated according to the end immediately propose whether it be to test the quality or the quantity of the current.

These instruments show the actual existence of an electri current by the deflection of their needles; from the directio they take we infer that in which the electricity was transmitte and lastly, from the magnitude of the angle of deflection we lear the intensity of the stream of electricity, and the degree of resistance offered to its conduction by any part of the battery (d. We shall presently show the relation subsisting between the deviation of the needle, and the intensity of the electric curren (§ 522.), at the same time we will explain the various modes o estimating the intensity of such currents; for the present w must take it for granted that, in general, every current has tendency to deflect the needle at right angles to its own line o direction, and that "cæteris paribus" those are the most powerfu currents which cause the greatest deflection. We must refer th reader to the section on Electromagnetism for a full explanatio of the theory on which the construction and use of these instruments rests; there also he will find an account of the various magnetic phenomena connected with them.

We shall at once proceed to describe the mechanical construction of such of these instruments as have come int most general use.

(a) *Jacobi's Compass Galvanometer*, *Fig.* 188., consists of

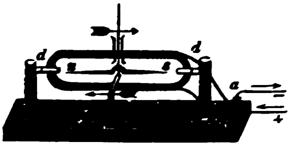
Fig. 188.



a common variation needle *n s* about 2 inches in length, under but close to which a copper wire about 1 line thick is carried, to the ends of which beyond the frame are fastened two mercury cups or binding screws *a*, by which this wire may be connected with the wires of the battery. The needle traverses the graduated circle: in using the instrument the needle should be set at 0, that the current beneath may deflect it from *s* to *n* or vice versa.

(b) *Schweigger's Multiplier*, *Fig.* 189., consists of a fine

Fig. 189.



copper wire *d d* bent into an oval shape, in the middle of which a variation needle *n s* turns, being either supported on a point or suspended by a thread. The two extremities of the wire are attached to two mercurial cups or binding screws *a a*, by means of which the wire of the galvanometer is made part of the electric circuit. That the current may be compelled to traverse the whole length of the wire without springing from one turn of the wire to another, it is wound round with several coils of silk, and the whole is coated over with a varnish of gum-lac. The action of the multiplier is considerably affected by the number of circuits made by the wire, the number being regulated according to the purpose for which the instrument is intended, whether to measure powerful or weak currents; in the former case the wire is passed round but once, or at most but a few times, in the latter it is passed round more frequently. The common multipliers have the wire passed round from 100 to 300 or 400 times; for particular purposes the wire has been made to perform 1000 circuits; for instance, Fechner's multiplier had a copper wire of 16,454 feet in length, which was bent round 12,076 times. Its thickness also is of importance, and the feebler the current to be measured the finer should the copper wire be. Lastly, in using this instrument, as also the compass galvanometer, it will always be best to place the wire in the direction of the magnetic meridian; the angle of deflexion may be measured by means of a graduated circle placed beneath the needle.

(c) *Nobili's Double Galvanometer* differs from the preceding chiefly in the application made of a double astatic needle. One of the most modern construction is represented in *fig.* 190. The multiplying wire is passed over and under a cylindrical frame, *a a fig.* 190 a., so as to leave a small space between the circuits of the wire for the reception of the lower needle. The upper needle, *n s fig.* 190., turns just above the circuits of wire, on which a graduated card is laid like that represented in *fig.* 188. The double needle is suspended by a fine thread *f r* of unspun silk, fastened at *p* to a pulley, from which a common thread *r p* runs down the metal stand *r p t* to a screw *x*, by which it is moved, and thus the needle is raised or lowered at pleasure. To bring the coils of wire

Fig. 190 *a.*

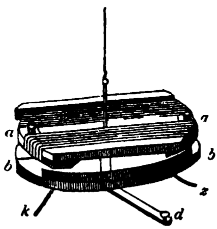
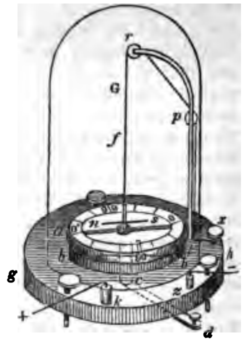


Fig. 190.



and the graduated circle into a proper position under the needle, the multiplier is fastened on a circular plate *b*, having in its centre a cylindrical plug which goes through a hole in the stand *g h* that supports the whole apparatus : to the end of the plug is attached a handle *c d* by which it is turned round. The two ends of the multiplying wire are connected with mercurial cups or binding screws *k z*, to which the conducting wires of the electric current are led. Three adjusting screws are placed beneath the stand to set the whole horizontally, and to secure the needle from draughts of air it is covered with a bell-glass G.

In these and all similar instruments the electric current must be sufficiently strong to overcome the directing influence of the earth's magnetism, or the needle will not be deflected. Hence it is evident that the sensibility of the apparatus, except that it may be increased by winding the wire a greater number of times, depends principally on the readiness with which the needle moves, and the smallness of its directing force. For these reasons it is better to suspend the needle by a thread than to rest it on a point, and we should use either single needles very feebly magnetized or an astatic needle. The following example will shew how greatly the power of the current circulating in the multiplying wire is increased in Nobili's multiplier. Suppose that the multiplier wire wound 333 times, then the original current would act on the lower needle with a force of 666, and on the upper with a force of 333 times what it would have possessed had the wire made but a single circuit; adding both together, with a force 999 or 1000 times as great. Both needles made, with a similar position of their poles, 57 vibrations in a minute, as astatic needles only 9. As the directing force of the earth's magnetism is proportional to the squares of these numbers (§ 449.), in the common needle this force will be 3248, and in the astatic needles 81, in the latter, therefore, it is 40 times less, and by consequence, the electric current acts with 40 times the force upon it. The deflecting power of the original current will therefore be increased by this galvanometer 1000 × 40 = 40,000 times.

(*d*) In a simple voltaic arrangement where the same connecting wire is used and the excited areas of the electromotors are equal, the deflexion of the needle will be greater, the greater the difference between the electrical tensions of the electromotors; this will evidently depend on the quantity of electricity set free by their contact and accumulated on their equal surfaces. Hence hydro-electric batteries of two heterogeneous metals and two different liquids (§ 505.) cause the greatest deflexion of the needle. In similar simple galvanic arrangements the deflexion increases with the increase of the electromotive surface acted on, but not quite in the same ratio, on account of the resistance to be overcome by the fluid in its passage from one element to another (§ 511.). In the same battery the deflexion of the needle decreases the greater the distance of the electromotors from each other in the intermediate liquid (§ 511.). In a compound battery, according to Ohm's law, when the resistance to conduction in the connecting wires of the multiplier is extremely small compared with that of the battery itself, the needle is not more powerfully deflected than by a single pair of plates (§ 511.).

Colladon was the first who proved that a stream of electricity, generated by friction, caused an analogous deflexion of the needle, thus furnishing additional evidence of the identity of frictional and contact electricity. To effect this we require a multiplier which makes a great number of circuits, and a continuous stream of the electric fluid; for this purpose the multiplier is interposed between a conductor running from the prime conductor of the machine to its cushion (a piece of wet tape will do very well); when the circuit is completed, set the machine in action; or charge a Leyden jar or battery by such a damp conductor, one end of it being connected with the outer, and the other with the inner coating of the battery. This last is the mode adopted by Faraday in his observations on electrical phenomena, in order to verify the contrast subsisting between frictional and voltaic electricity with regard to quantity. A very small voltaic battery consisting of one platinum and one zinc wire, $\frac{1}{18}$th of an inch thick, immersed in very slightly acidulated water, and held at a distance of $\frac{1}{3}$rd or $\frac{1}{2}$ an inch asunder for 3 seconds, deflected the needle of a galvanometer as much as the charge of an electrical battery of 8 jars which had been loaded with 30 turns of a powerful machine. When he used 15 jars and charged them with 30 turns of the machine, the quantity of electricity in the battery was the same, but its tension or density was rather less, and when discharged it caused precisely the same deflexion of the needle as in the first experiment; on turning the machine 60 times, the battery caused a deflexion of the needle twice as great as at first.

§ 513.

2.) *Luminous phenomena* occur at the moment when and at the points where the poles of a battery are connected by means of the connecting wires. The electrical spark is very small and rt, for it is emitted when the wires are almost in contact with poles of the battery ; its colour and the intensity of its light end on the metal by which it is rendered visible; probably s difference is owing to a partial combustion of the metal, at points where the electric current passes from the poles to the es When the connexion is established by means of mercury, light is white and brilliant, if by means of iron or steel, it of a reddish hue, with small scintillations radiating in all ections.

A spark of this kind will be emitted from a small hydro-ctric arrangement of two plates only, but if the battery consist several pairs of plates, the spark will be brighter; its intensity, wever, depends rather on the extent of surface in contact with fluid, than on the number of pairs of plates.

Very brilliant sparks may be obtained by means of a Grove's battery, of one zinc and one copper plate of ordinary dimensions, or with a few pairs of Bunsen's carbon battery; with either of these the following experiments may be performed.

EXPERIMENTS. 1.) Bring nearly together the amalgamated ends of the polar wires, while the battery is in a state of activity, a small, white, starlike spark will be seen accompanied by a crackling noise like that which attends the emission of a feeble electrical spark.

2.) Plunge the end of one of the wires into a small vessel of mercury, and bring the other near the surface of the metal. A similar spark is emitted just before the point touches the mercury, on which a small black speck may be seen where the spark struck it.

3.) The spark obtained from an amalgamated point is visible under water or in the flame of a candle.

4.) Fasten a fine sewing-needle to the end of one of the wires, and touch the other pole with the free end of the needle ; a starlike red spark will be emitted. A continued stream of these sparks may be obtained by connecting a small round or triangular file with one pole, and presenting to it and removing from it with great rapidity the point of a copper wire attached to the other pole.

5.) Coat the ends of the connecting wires with soot, by holding them in the flame of an oil lamp, and the sparks will be both larger and brighter; they will be obtained of the greatest intensity by holding the points of the wires in the flame opposite to each other.

Nobili says, that, in performing experiments of this kind he obtained the brightest sparks by connecting the two ends of the battery with a long spiral copper wire, or with a wire insulated by being wound round with silk.

§ 514.

3.) *Thermal phenomena.* — Heat is elicited when an electric current is generated by completing the circuit in a voltaic pile, it manifests itself in the connecting wires, in the electromotors, and also in the intermediate liquids. The intensity of the heat is regulated rather by the size than by the number of the plates; it is greatest in those batteries which have the greatest difference of tension (platinum and carbon batteries). This effect seems to depend more on the quantity of the electric fluid than on its intensity; the latter does, however, exert some influence, as Pfaff informs us, that with twice or three times the number of plates, a wire became hotter than when it was connected with a single pair; the heat is further dependent on the conducting power of the body, bad conductors of equal length and thickness with good ones becoming much hotter than the latter. Many attempts have been made to explain the causes by which these thermal phenomena are excited and modified. This has been done, on the whole, in the most satisfactory manner by Ohm, who assumes, that the degree of heat depends on the intensity of the electric current in the interior of a body, and also on its conducting power; according to Riess's experiments, it has been ascertained that the relative power of metals for acquiring electric heat, is directly as their retarding powers, or the resistance they offer to its conduction, and consequently, inversely as their capacity for heat and their density; these magnitudes may therefore be expressed by a fraction having for its numerator the retarding force, and for its denominator the capacity for heat and the specific gravity. These thermal phenomena seem further to be a result of the resistance which the conductors offer to the union of the ± electricities; whence, in addition to all other causes, its intensity will be greater, the greater the quantity of electricity neutralized in the electric circuit.

In the metal wires by which the poles of a battery in action are connected, the heat is manifested by the incandescence of the metal, or even by its combustion, the heat being the most intense in the finest wires.

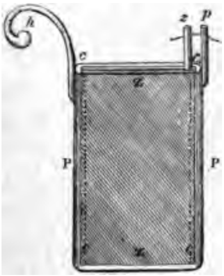
In very powerful batteries, such as Children's, Hare's and Strating's deflagrators, or even in platinum and carbon batteries, of considerable size, and from 10 to 20 pairs of plates, the development of heat is so great that substances, which are hard enough to resist the action of any furnace, are readily fused and burnt. To this may be added the remarkable fact, that these phenomena occur under circumstances in which we should not have expected them to happen, and under which they could not have been brought about by the ordinary process of combustion;

r instance, wires and charcoal points may be made red hot ıder water, and metals may be fused and burnt in vacuo, and close vessels filled with gases which put a stop to the chemi- l process of combustion, such as nitrogen and carbonic acid ıs.

The thermal influence of the hydro-electric current may be shown in the following experiments: —

EXPERIMENTS. 1.) *Wollaston's thimble apparatus* is the smallest hydro-electrical apparatus ever constructed, by which the heating powers of the current have been made visible. This miniature battery is represented in *fig.* 191. of its actual size. P is a strip of thin silver or platinum leaf, bent so as to embrace an amalgamated zinc plate Z, at a distance of about a line. The insulation between the metals is effected by means of little pieces of cork thrust between them; *z* and *p* are the two copper or silver polar wires slit at the ends, into which is let a very fine platinum wire not more than a line in length. The wire hook *h* serves for suspending this little battery in a glass containing some dilute sulphuric acid (1 part acid to 4 of water). The current transmitted through the wire between *p* and *z* sets the latter in a state of incandescence.

Fig. 191.



Batteries of platinum and carbon are best adapted for producing powerful incandescence and combustion, especially on account of the steadiness of their currents. With one of these batteries of from 2 to 6 pairs of plates, each containing a surface of from 10 to 20 square inches of platinum or carbon, very brilliant effects may be produced. Nearly equal effects accompany the use of a battery of double the number of Hare's zinc and copper spirals, each of which should have a copper surface of from 150 to 300 square inches; it continues, however, in action but a short time, as after a quarter of an hour the intensity of the current is perceptibly lessened, whilst the other battery will maintain its action for an hour or more unimpaired. The following are the most important results which may be obtained from these batteries: —

2.) Connect the poles of the battery by means of a very fine iron or platinum wire, several inches in length, or a piece of thin watch-spring will do, and the metal will become red hot. Shorten the wire, and it will become white-hot and then melt; now use a stouter piece of wire, and the heat attained will be less. Substitute silver or copper wire of equal length and thickness with the iron or platinum wire that was raised to a red heat; in consequence of its better conducting power, it will merely be made hot without being melted; whereas a stouter and longer piece of either tin or lead would readily fuse.

3.) Establish a connexion between the poles by means of a stouter platinum wire pointed at the ends; fusion will take place at the points of contact, to which the wire will in a manner be soldered. The effect will take place even under water.

4.) Conduct the connecting wire through a small quantity of some saline solution, placed in a watch glass or an earthenware cup; the liquid will presently boil, and those parts of the wire beyond it will be made red-hot.

5.) Sulphuric æther, alcohol, phosphorus, gunpowder, and other combustible materials, may be ignited by making the connecting wire to pass through their mass, or to touch some part of their surface.

In consequence of their possessing this property, hydro-electric batteries have been used to spring mines, even under water, with success. Experiments on this mode of blasting were first made successfully by Hare, in N. America, in 1832, and by Morgan, who applied it to the blasting of rocks, and to other mining operations. Its applicability to the exploding of mines in war was proved two years later, at Petersburg; similar experiments have since been performed with equal success in the Netherlands (1837), and at Chatham, in 1838 and 1839, by General Pasley, especially to investigate explosion under water; the results have fully established the certainty and safety of these modes. In the Netherlands an inconstant but powerful Wollaston's battery, of 2½ square feet effective copper surface, at Chatham, a Daniell's constant battery of 10 cells, each containing an effective copper surface of 230 square inches, were used for the experiments.

On the 26th Jan., 1843, a blasting of rock by this process was performed on a very large scale, when the Round Down was blown up in the neighbourhood of Dover. Cubitt, the engineer employed by the London and Dover Railway Company, in the construction of their line, deposited three charges, in all 18,000 lbs. of powder, so that the middle one was 70 ft., and the others each 55 ft. from the extremities of the cliff. The powder was fired by means of 18 Daniell's and 2 common batteries of 20 pairs of plates, at a distance of

1000 feet, it having been previously ascertained that it might have been fired even at a distance of 3300 feet. (Probably a few Grove's or Bunsen's batteries would have answered equally well.) 300,000 cubic yards of chalk, weighing 600,000 tons, were set in motion at once, and the cliff was considerably lowered for the length of 500 feet.

It is of great importance that these results can be attained with perfect safety and at considerable distances (Basse, at Hamela, raised a piece of platinum wire to a state of incandescence at a distance of 4000 feet); as also that the conductor may be carried through the air, or on or under the surface of the earth, nay, even through water, without the action of the battery being thereby impaired. This mode of blasting may be more generally used since the adoption of small carbon and platinum batteries; the great expense having formerly been an obstacle, as the early experiments were performed with large deflagrators.

Jacobi, to whom we are already under such considerable obligations for his numerous experiments and theoretical investigations in this department of science, was employed, in 1842, in conducting a series of experiments for discovering the best mode of conveying hydro-electric currents for telegraphic purposes. In examining how far water might be substituted for a metallic conductor, he arrived at the important results given below. He first established a conduction of this nature between Oranienbaum and an arm of the Gulph of Finland, a distance of 5600 feet, one half through water, and the other through an insulated copper wire, ¾ of a line in diameter, which was carried over a dam, so that the entire length of the connexion was 11,200 feet. The electric current was excited by a Grove's battery, of 24 pairs, and a common voltaic pile of 150 6-inch plates. A zinc plate of 5 square feet was sunk in the sea from one pole of the battery, and at the opposite end of the connecting wire a similar plate was sunk in a canal joining the sea. Charcoal points were used for completing the circuit of the Grove's battery; these, and also a fine platinum wire, were made red-hot, and these phenomena appeared to be more intense than when copper wires were used as conductors. In a later experiment he employed a similar conduction, the distance in this case being 9030 feet, namely, from the winter palace of the emperor to the Fontanka, near the Obuchowski bridge. One of the conductors was a copper wire carried under ground, the other was the Neva itself, in which a zinc plate 5 square feet was sunk beneath the surface of the river. At the other extremity a similar zinc plate was immersed in a small pond, whose level was 5 or 6 feet above the Fontanka, from which it was separated by a flood-gate. The battery consisted of 25 small Daniell's constant batteries, by means of which, notwithstanding the great extent of water, all the galvanic and magnetic phenomena were produced. At Lenz's suggestion, a different species of conduction was tried between the same stations. A connexion was established with a point of the iron roof of the winter palace, which was connected with the ground by means of conducting rods, and the current was carried equally well along the moist earth.

6.) To the end of one of the wires fasten a small strip of gold or silver leaf, or of copper or zinc foil, or a small piece of extremely thin tin or lead, and establish a contact between any one of these and the opposite pole, or one of the plates connected with it, and combustion of the metal will ensue, attended with a hissing noise, and with variously coloured light. Gold burns with a blueish white light, and leaves behind a dark brown oxide. Silver burns with a bright sea green colour, and emits a greyish vapour. The combustion of copper gives out a blueish green flame, mingled with red sparks and a greenish smoke. Zinc burns with a dazzling white light and white vapour; tin with red sparks, and lead with a purple flame. This combustion of the metals is rendered still more vivid, by connecting one pole with mercury and placing the metal that is attached to the other pole in contact with the mercury.

7.) The most splendid phenomenon of this kind is the combustion of charcoal points. Pointed pieces of the residuum obtained from gas retorts will answer best, or Bunsen's composition may be used for this purpose. Put two such charcoal points in immediate contact with the wires of your battery; bring the points together, and they will begin to burn with a dazzling white light. The charcoal points of the large apparatus belonging to the Royal Institution became incandescent at a distance of $\frac{1}{30}$ of an inch; when the distance was gradually increased till they were 4 inches asunder, they continued to burn with great intensity, and a permanent stream of light played between them. Professor Bunsen obtained a similar flame from a battery of four pairs of plates, its carbon surface containing 29 feet. The heat of this flame is so intense, that stout platinum wire, sapphire, quartz, talc and lime, are reduced by it to the liquid form. It is worthy of remark, that no combustion, properly so called, takes place in the charcoal itself, which sustains only an extremely minute loss in its weight, and becomes rather denser at the points. The phenomenon is attended with a still more vivid brightness, if the charcoal points are placed in a vacuum, or in any of those gases which are not supporters of combustion. Instead of two charcoal points, one only need be used if the following arrangement is adopted: lay the piece of charcoal on some quicksilver that is connected with one pole of the battery, and complete the circuit from the other pole by means of a strip of platinum. When I have used a piece of well-burnt coke in the manner just described, I have obtained a light which was almost intolerable to the eyes.

These thermal phenomena happen not merely at the points, as in the experiments described above, but also in the battery itself, both the electromotors and the connecting liquid becoming heated, the elevation of temperature of these latter being much less than that of the connecting wires, because the transverse section of their conducting surface is much greater.

§ 515.

4.) *Physiological effects.* — The physiological effects of the hydro-electric current on the nerves and muscles of animals are essentially the same as those produced by frictional electricity, modified, however, in some degree, by the continuous action of the current; they are also characterised by the presence of some chemical influence, which excites the organs of taste and sight in a remarkable manner. Very small batteries are adequate to excite the organs of taste and sight, but a large apparatus is needed to produce any perceptible influence on the sense of touch, so as to cause the nerves and muscles of the human body to contract when it forms part of the circuit. These effects may be rendered almost indefinitely more powerful by increasing the number of plates, whereas the magnitude of the excited surface exerts *no perceptible influence* on them. Hence, to produce a shock, we should use the common voltaic pile, or one of Faraday's or Young's batteries (§ 506.), with plates of about 2 square inches. The most efficient batteries, with large plates, and even those of platinum and charcoal, which exhibit to perfection the remarkable phenomena of incandescence, seem almost totally ineffective when used to produce this other class of effects. This strongly-marked distinction in the capacities of batteries consisting of a number of small pairs of plates, and those which are composed of a few large pairs admits of a satisfactory explanation by Ohm's law. (§ 511.) In any case when it is desired that the current should exert a powerful influence on some bad conducting substance, the density of the electricity must be increased as much as possible by employing a great many pairs of plates, and thus the resistance offered to the conduction and transmission of the fluid through its circuit by the interposition, for example, of the human body, is more easily overcome : this end would not b tained by increasing the quantity of the electricity, whicl might do, either by increasing the effective surface, or by more powerful combinations, because, by either of these mean should reduce only the resistance that we meet with in the tery itself, and that, compared with the resistance of the conducting substance that forms a part of the circuit is, afte but very small. So, also, we can easily explain why these e are rendered still more powerful, if that portion of the h frame which is enclosed within the wires be moistened with liquid that is a good conductor: the effect is heightened further, if large metallic surfaces, instead of merely the poin the wires, are brought into contact with the body : by eith these modes, the strong resistance which the human frame to the transmission of the electricity is much lessened.

Suppose we use a single pair of plates, whose electr tive power we will call 1, and that the resistance of th man body which forms a part of the circuit is 100 greater than that of the pair of plates, then, by Ohm's mula, the effect of the current on the body may be expr by the fraction $\frac{1}{1+100} = \frac{1}{101}$. Next use a battery co ing of 100 such pairs, and its effect will be represent $\frac{100}{100+100} = \frac{1}{2}$, which is much greater than that of the s pair; now if we were to employ a single pair of plates an electromotive force 100 times greater than that of th first spoken of, or, in other words, one whose resistan conduction shall be 100 times less than that of the for the effect of its current on the human frame would be $\frac{1}{\frac{1}{100}+100} = \frac{1}{100.01}$ which is but very little more than t the first pair, whose electromotive power we supposed only $\frac{1}{100}$th part of the power of the latter pair.

The following are a few of the principal experimen means of which these effects of the voltaic current m verified.

Experiments (1). *Galvani's fundamental experimen* serves the first place in this list. Touch the nerve of a frog's spine and the muscle of one of his thighs with tw ferent metals, *ex. gr.* with zinc and silver, or zinc and c wires, bring their points into contact, and the frog's le become violently contracted. These muscular contra will be repeated as often as the connection of the wires established, and in young frogs especially they may be ceived even an hour after death. Bailey substituted complete success the hind leg of the common grasshopper for that of a frog.

2.) *Imparting the shock to a leech.* Lay a silver coin, a five-shilling piece will do very well, on a larger plate of zinc, either metallically pure or amalgamated, and on the coin place a live leech. When he moves so as to touch the zinc, and thus establish a connexion between this metal and the silver, he will receive a shock, and will instantly recoil.

3.) *The nerves of taste excited in the human subject.* If the hydro-electric circuit be completed by the interposition of the tongue, one pole of a battery being placed in contact with the tip of the tongue, and the other pole being made to touch a moistened part of the face, the metal on the tongue will excite a peculiar taste, varying according as it conveys either + or — electricity; the former produces a sourish cool taste, but the latter causes a bitterish burning or alkaline taste; this is owing to the chemical decomposition of the saliva by the electric current in its passage. The effect may be produced by means of a very simple galvanic combination, namely, by laying a silver spoon and a polished strip of zinc one above and the other under the tongue, and then bringing the ends of the metals into contact. The sensation will be more powerful if a small battery of from 10 to 12 pairs of plates be used.

4.) *Excitement of the nerves of sight.* A peculiar flash or luminous appearance will be produced by bringing the poles of a voltaic battery to two parts of the body between which the eyes are situated, as, for instance, the corners of the eyelids; or a similar effect may be produced by holding one of the wires with a moistened hand, and planting the point of the other wire against the edge of the lid, or against a piece of tin-foil held over one of the eyes, which is to be closed. The phenomenon occurs on completing the circuit, and again in a lower degree when the connexion is broken. A similar but more feeble impression is produced by placing a silver spoon between the gums and one cheek, and a strip of zinc held in a like position on the other side, the circuit is completed by making the metals touch outside the mouth. The intensity of the flash is heightened by using a small pile of some 10 or 12 pairs, and establishing a connexion by means of the hand, the wire being brought against some moistened part of the face.

5.) *Influence on the organs of hearing.* Bring the poles of a small battery to the interior of both ears, and at the moment when the connexion is established, a slight shock will be felt in the head, and a roaring sound will be heard so long as the wires are held in place.

wise commence almost instantly, the potassium should be put in petroleum, or Barbadoes tar.

By availing ourselves of the affinity of mercury, the alkalies may be reduced with apparatus of mean power: according to Pfaff's and Herschel's experiments with piles of not more than 10 pairs of plates. To perform this experiment, scoop out a pretty deep hole in a piece of moistened caustic potash, and fill the cavity with mercury; lay the potash on a platinum plate which is connected with the + pole of the pile, and put the quicksilver in contact with the – pole whose wire must be either iron or platinum, on it the mercury will speedily be deposited as a solid amalgam. According to Berzelius, it is best to pour a concentrated lye of caustic potash, the solution being such a saturated one, that it shall contain some potash undissolved, over the mercury, which should be held in an earthenware saucer, then conduct the negative wire to the mercury, and the positive platinum one into the lye; the quicksilver will become thicker and thicker, and small metallic crystals of the amalgam of potassium will be formed, their figure being apparently cubical.

Sodium may be decomposed as readily as potassium, by the aid of mercury, if we use some of its salts, especially either sulphate of sodium, or chlorate of sodium; the alkaline earths may also be reduced by means of mercury, which combines with their metallic radical so as to form amalgams; the earths will, however, require rather powerful batteries.

By this process we may obtain the *amalgam of ammonia.* Berzelius's method of obtaining this singular substance is the following. The experiment may be performed, he says, in the same manner as the reduction of potash, with this difference only, that a concentrated solution of sal ammonia should be poured on the mercury, which will begin to swell up and continue to do so until it attains from 5 to 6 times its original volume, the metal will acquire a silvery whiteness, and will be of the consistency of butter. This amalgam may be procured in larger quantities, and of a drier form, by scooping out a hole in a piece of sal ammonia, moistening it with a little water, and pouring a small quantity of quicksilver into the cavity, then connect the mercury by a platinum wire with the – pole of the battery, a similar wire being made to join the moistened sal ammonia with the + pole, passing as near as possible to the quicksilver without coming into actual contact with it. The globule of quicksilver will increase gradually till at last it extends far beyond the cavity which at first contained it. This amalgam is procured most copiously and readily, if the quicksilver employed in the last experiment to accelerate the reduction be combined with a very minute portion of potassium or sodium, and the battery be then arranged as described above.

Fifth Expt. Transmission of the decomposed elements through substances which have a low conducting power, and through liquids which have a chemical affinity for them. — The transmission of the substances through porous bodies of low conducting powers, and through fluids with which they might have been expected to combine chemically, so that they arrive at the respective electrodes of the battery is certainly one of the most extraordinary phenomena of electrolysis.

The third experiment may serve as an illustration of the transmission of the elements through porous bodies, as bladders, earthenware, and the like; for, on referring to that experiment, it will be seen that the current and the electrolysis of the metal are transmitted through the bladder. This process may be rendered visible by filling the glass tube with a solution of sulphate of sodium, and the outer glass with water, then colour both the liquids blue, with some vegetable tincture; and that which contains the negative metal will become green, and that in which the positive metal stands will be red. The like obtains in those batteries which have two fluids separated by means of a porous earthenware cell.

The products obtained by the decomposition of the substance electrolysed, pass to their respective poles, through different liquids which communicate with each other, as may be shown thus:

Fill two small glass vessels with the liquids to be decomposed; connect the vessels by means of some threads of cotton. In like manner interpose another vessel, also containing some decomposable liquid, between the first two; connect it with them by thread; into the outer vessels bring the poles of a galvanic battery, and the following results will be observed.

In whatever manner you may have distributed the fluids in the different glasses, after some time their electro-negative element will have accumulated in the glass that contains the positive electrode, and the positive element in that which is connected with the negative electrode. Immerse, *ex.gr.*, the positive wire in a solution of sulphate of sodium, and the negative wire in pure water, the acid will collect about the former and the base about the latter: the base must therefore have been carried over into the other glass. This interchange of the substances may be made apparent by dyeing the liquids in the two vessels blue, with tincture of violets.

The acid or alkaline elements, in their passage through the middle glass, do not in the least degree affect the liquid it contains.

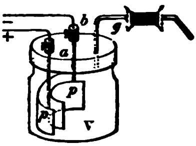
This transmission obtains only when they have to pass through a fluid with which, but for the voltaic pile, they would form a solution.

§ 517.

Faraday's comprehensive investigations led him to discover two important laws in electrolysis, the accuracy of which has been confirmed by the subsequent researches of Professor Jacobi. He found that, "*the chemical power of a current of electricity is in direct proportion to the absolute quantity of electricity which passes*," or, expressing it according to Ohm's law, "*to the quantity of electricity which passes during the process of decomposition through the transverse section of the battery.*" Hence it follows that the same quantity of electricity will always decompose an equal portion of the same substance: so the quantity of the elements obtained in any given unit of time will depend on the density or intensity of the current employed. Hence if the intensities be twice, three times, or *n* times greater, twice, three times or *n* times as much of the body electrolyzed will be decomposed. If the mass and density of the electricity emitted, that is to say, if the electromotive power and its intensity, remain unaltered, the effect of the current or the quantity of the substance decomposed will be the same; but if one or both of these factors be altered, the degree of chemical decomposition will be proportionally affected.

If we take into account the time required to produce a certain effect, we may use any substance to measure the *intensity* of the electric current, if it possesses the following properties, viz. that it is easily resolved, that its structure is perfectly uniform, and that the products yielded by its decomposition admit of being readily measured; the reader will bear in mind that the *quantity* of electricity discharged in a current is measured by means of a galvanometer. Faraday first constructed an apparatus for measuring the intensity of the electric current, and gave to his invention the name of a *volta-meter.* The electrolyte which best fulfils all the requirements is water, and any arrangement in which a stream of electricity is made to decompose it, if furnished with the means for measuring the quantity of gas thus generated, may be regarded as a volta-meter.

Fig. 194.



In *fig.* 194. we have represented a very simple and efficient kind of volta-meter. V is a glass cylinder capable of containing from two to four ounces of water: it is covered with a well-polished piece of plate-glass, (the lid may, however, be made of metal, if care is taken to insulate the wires *a* and *b*, which are carried through it). *p p* are the two electrodes, which consist of two plates of platinum or iron placed parallel, and as near together as possible. The wires to which these plates are soldered pass air-tight through the lid, and are connected by two binding screws with the wires of the battery. *g* is also a glass tube, fixed air-tight in the top of the cylinder; it is meant to be placed under a graduated glass tube in which the oxy-hydrogen gas is taken off as it is liberated by the decomposition of the water. According to Poggendorf's experiments, if the electrodes be of platinum, it is best to mix the water with sulphuric acid, but if of iron, it is advisable to add, instead, a tenth part of caustic potash.

The other law, equal in importance to the first, is this, "*the mount of electro-chemical action is a constant quantity, i. e. would lways be equivalent to a standard chemical effect founded upon rdinary chemical affinity,*" in other words, *the quantities of the roducts which any stream of electricity disengages by resolving arious electrolytes are to each other in the same ratio as that in hich they combine chemically.* This is known as *the law of definite ectrolytic action,* in accordance with which Faraday has called ose masses of bodies which combine with equal definite quanties of electricity *electro-chemical equivalents.* From the above w we may deduce the following important conclusion, that, in nsequence of the proportionality that subsists in all decompotions effected by the same quantity of electricity, reckoning cording to the atomic weights of the bodies resolved, *the atoms 'all substances whatever must take up or hold, in an equally latent te, equal quantities of electricity.*

From a number of experiments originally performed by Faraday, and since repeated and modified by Pfaff, it was ascertained, that for every atom of water decomposed by a hydro-electric current in a volta-meter, one atom of any other electrolyte or ion would be resolved by the same stream in its passage through another cell containing it. Thus Faraday found in transmitting a current of electricity through a volta-meter which had an amalgamated zinc plate for its positive and a platinum plate for its negative electrode, that whilst one part by weight of hydrogen was evolved at the latter, 32·3 parts of zinc were dissolved at the former. But the equivalents of hydrogen and zinc are to each other as 12·48 : 403·23, or as 1 to 32·3. The current would produce precisely the same effect if conducted through any similarly arranged apparatus, *ex. gr.*, in a single pair of plates of amalgamated zinc and copper, or in a compound voltaic battery, for every equivalent of hydrogen that is evolved, one equivalent of zinc would be dissolved, so that the consumption of the metal would be always equivalent to the degree of electrolysis reached.

§ 518.

The power of the electric current to effect chemical decomposition manifests itself, as has been already remarked, equally in every member of a voltaic pile. This chemical action exerts a perceptible influence on the effect of the current generated by a hydro-electric battery; its influence being greatest on those batteries in which either a dilute acid or some saline solution is employed as the exciting liquid to act upon the metals. These batteries in consequence of their combination possess in the first instance but a feeble force, for the same fluid is in contact with both the electro-positive and the electro-negative metal, consequently the electromotive power of the two metals is similarly though unequally impaired; their influence therefore in generating the current corresponds to the difference in the electromotive excitement of the two metals. (Comp. § 505.) The elements of the liquid, too, which accumulate about the metals tend to diminish still more this electromotive difference. The hydrogen, the bases, or the metallic oxydes collect about the negative metal, whilst the oxygen, the chlorine, and the acids gather around the positive metal: the former is therefore coated with positive substances: it is thereby polarized and rendered less negative, and the latter by oxidation becomes less positive: in proportion as these changes are brought about in the electromotive fluids, and in the metals on which they act, the difference of tension will be diminished and the current will be enfeebled. Fechner's opinion is, that the diminution in the fluid's conducting power that attends its decomposition contributes in the highest degree to reduce the strength of the current.

These influences tell less powerfully on Daniell's, Grove's, Bunsen's, and the other batteries of more modern construction, in which each electromotor stands in contact with a fluid that excites it in a manner, the antagonist of that in which the other electromotor is excited by the fluid in contact with it. (Comp. § 505.) Hence the initial tension is greater than in such batteries as have but a single fluid: again the products obtained by omposition diminish but little, or not at all, the difference of sion between the electromotors, as will be seen from the fol- ring considerations. If some sulphuric acid but slightly uted be used in one of these batteries to act upon the amal- mated zinc, the oxide of zinc formed by the oxygen which is ren off, is dissolved as rapidly as it is produced by the sulphuric id that is in contact with it, so that the surface of the zinc mains unchanged; the electromotive fluid in the meanwhile comes gradually converted into a solution of sulphate of zinc, hich, as both Pfaff and Poggendorf ascertained, is nearly or ite as effective as the sulphuric acid; the electromotive pro- rties of the zinc are therefore but little, or not at all, impaired the continued action of the battery. In Daniell's battery, in hich a solution of sulphate of copper is made to act on the pper, the process of decomposition is similarly advantageous; the positive hydrogen emitted at the copper reduces the oxide copper formed simultaneously with it, and which deposits elf as the pure metal on the negative copper surface. The elec- ical tension of the apparatus is therefore maintained at the me point, so long as care is taken that the solution of copper all be a saturated one. In Grove's and Bunsen's batteries, where ncentrated nitric acid is used to act on the platinum and carbon, ese electromotors are not polarized and enfeebled by the hy- ogen given off at them, because at the very instant it is gene- ted, it combines with one equivalent of oxygen from the nitric id and forms water, and a corresponding portion of nitrous acid capes as a gas; thus, as Schönbein expresses it, the platinum, d by analogy the carbon also, become *depolarized* and relatively alted in their electromotive functions. To this the more recent tteries are indebted for their superiority over the older ones, nce the effect of their current is for a length of time unimpaired, ey are therefore fairly entitled to the appellation of *constant tteries.*

§ 519.

Within the last few years the decomposition and reduction, by eans of the hydro-electric current, of metals held in a state of lution, has led to several important discoveries which have been riously applied to industrial purposes. Such are the arts of *ectrotyping* or *galvanoplastic*, *galvanography* or *electrography*, nd *electro-plating.*

Electrotyping was simultaneously (1839) invented by Jacobi, f Petersburg, and Spencer of Liverpool. By this process copper sts are obtained of objects. It was observed that in a Daniell's ttery a regular deposit of copper was formed on the negative etal by the secondary action of the solution of sulphate of battery, that can be regulated by a galvanic compass (§ 512.); the battery *fig.* 195. is furnished with a magnetic needle *ns* placed on the strip of metal *bc*. The constancy of the strength of the current is best maintained by keeping up the solution of copper in a saturated condition, which may be effected either in the manner named in describing the apparatus, or as has been already shown in § 505.

We have a remarkable illustration of the perfect accuracy of an electrotype copy, owing evidently to the extreme minuteness of the particles of copper, in the fact that an electrotype copy of a Barton's Iris-button (§ 327.) produces as fine an effect by the prismatic interference as the original itself.

Electrography or *galvanography*, which was first discovered and applied by Osann, depends on the opposite effect of the electric current to that on which electrotyping rests. In this process the resolving power of the current is used to bite in figures and drawings on a copper plate, which is placed in a cell, and acts as the positive electrode; the marks on the plate are made by the deposit of sulphuric acid; all those parts on which it is not intended to act are therefore coated over in the same manner as in preparing the ordinary mezzotint engravings.

Electroplating is, properly speaking, only a modification and extension of electrotyping, inasmuch as it consists in covering metallic objects with a coat of solid gold, silver, platinum, copper, zinc, &c., of any thickness that may be desired. De La Rive first showed the application of galvanic electricity to this purpose. Dr. Böttger introduced some alterations in the details, which have been still farther simplified by Dr. Elsner. In the main it consists, like the electrotype, in covering with one or other of the metals named above some object which acts as the negative electromotor in an apparatus resembling that depicted in *fig.* 195.; the object to be electro-plated is immersed in a solution of the metal with which it is to be covered; this solution exerting on it an electromotive influence, so electrolyzes it by the current which is generated, that the metal disengaged from the solution is regularly thrown down and adheres firmly to the immersed body. Elkington's and Recolz's method, which has come to be generally adopted, differs from that just described in carrying on the transfer of the metal in a distinct cell. According to their plan the metallic solution is contained in a vessel of glass or earthenware, the size of which is proportioned to the dimensions of the object to be gilt or silvered. Immerse the object completely in the fluid, and connect it with the — pole of a constant battery of from 2 to 6 pairs of plates; it will thus form the negative electrode; suspend a plate of the same metal as is held in solution and of corresponding size with the object you desire to cover opposite to it he liquid, and it will act as the + electrode. Any gilt or silvered le may be deprived of the metal with which it is coated by g it as the positive electrode and a similar piece of metal for the ative electrode; the plating will thereby be dissolved and be sferred to the latter. Solutions of the cyanide of the various als are most commonly employed for this purpose; Dr. le says the simplest mode of obtaining them is to pour an eous solution of cyanide of potassium (1 part of the latter to of water) into a glass, in which suspend the metal, rolled as as possible, as the positive electrode, and at the distance of a inches hang a copper wire as the negative electrode, taking that it shall not sink more than ½ an inch below the surface he liquid. Keep the solution at a temperature of about 100°, in the course of 24 hours the electric current generated will e dissolved the metal: when the tip of the copper wire which d as the negative electrode begins to be covered with a deposit he dissolved metal, the solution is strong enough.

The tinning of iron, steel, and cast-iron must of necessity be highly important for many purposes connected with the arts, and we may even anticipate the application of the process to protect fire-arms and ammunition from the action of weather.

On this principle Becquerel conducted his experiments for obtaining in a crystalline form many bodies which had not previously been procured in that state. For this purpose a very delicate stream was conducted by fine wires into the fluid that was to be decomposed; on which after a considerable time, extremely minute particles were deposited in the form of beautiful crystals. Batteries such as that represented in *fig.* 193. will be found well suited for this experiment.

If a feeble current be applied to polished plates of platinum, el and silver, by using them as electrodes, and immersing them an electrolytic fluid, certain figures will be visible on them, led after their discoverer *Nobili's Electro-Chemical Figures;* best solutions are those of acetate of lead, acetate or sulphate copper, and acetate or chlorate of manganese; using then a lished plate of any of the three metals named above as one ctrode, take a fine-pointed platinum wire as the other electrode, d bring it within one or two lines of the plate. The elements

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NOTE.—Mr. Walker has succeeded in reducing the *alloys* by voltaic eleccity. His process is "to prepare a strong solution of cyanide of potassium, d commence electrolyzing it, by means of a copper anode; as soon as copper gins to be dissolved, the copper anode is removed, and its place supplied th one of zinc; after the action has continued for some little time, brass ll be liberated on the cathode. The solution is now ready for use, and is erated upon by two or three Daniell's cells, and with a brass anode. By milar means alloys of gold and copper, or gold and silver may be deposited." *Athenæum*, June 28. 1845.

obtained by the decomposition of the liquid will be deposited on the metal plate, generally in the form of concentric circles whose centre is exactly opposite to the point of the wire; their colours are various, very much resembling Newton's prismatic rings (§ 327), and so firmly fixed that they cannot be removed even by washing the metal with nitric acid. It has been remarked that with regard to many of the solutions (*ex. gr.* acetate of lead, acetate and chlorate of manganese), the figures are more beautiful if the plate is used as the + electrode, whereas with others (as, *ex. gr.*, acetate of copper) they are most brilliant if the plate is the — electrode. After a figure has been formed reverse the poles and it will gradually vanish; if the action be continued the opposite electrical figure will appear.

The above remarks may be illustrated by the following experiments:—

First Expt. According to Fechner, Nobili's figures may be produced by the feeblest current of a simple voltaic battery; lay a small plate of polished platinum or steel in an earthenware saucer, and pour over it a solution of acetate or sulphate of copper to the depth of a few lines, and touch the plate with a pointed strip of zinc the other end of which is in the fluid.

Second Expt. These figures will be obtained with increased brilliancy and beauty by using a constant battery of from two to six cells. Then, according to the solution employed, connect the plate with either the + or — pole of the battery, and bring the pointed platinum wire which conducts the electricity of the other pole to within a couple of lines of the plate. As soon as the electric circuit is completed the action of the platinum point commences and rapidly extends itself over the whole plate.

§ 520.

Hydro-electric currents are capable, not merely of bringing about chemical combinations and decompositions, but also of impeding such changes as, according to the ordinary laws of affinity, would ensue in a mode exactly opposed to the tendency of the current. Thus to guard a metal against the chemical action of an acid or a saline solution upon it, all that is necessary is to place it in contact, or to combine it with some other metal in the fluid, which may act as the positive electromotor when in contact with the metal you desire to protect. The oxydizing and dissolving elements of the fluid are deposited on the + metal, whilst only the positive elements are given off at the — metal. In this manner iron, copper, tin, lead, and silver are secured by means of c against the chemical action of sulphuric, nitric, and muriatic ds, as well as gold and platinum against the dissolving power nitro-muriatic acid. Sir H. Davy successfully applied this nciple in the means he employed for protecting the copper ttoms of vessels against the corroding influence of the salt-ter; he connected plates of zinc, cast or wrought-iron, with the pper sheathing to the extent of from $\frac{1}{120}$th to $\frac{1}{101}$th of its entire rface.—Sometimes disadvantages are found to attend from e deposit of positive elements on metallic surfaces, as, for in-nce, leaden water-pipes occasionally become choked at the joints the deposit of lime held in solution in the water.

Third Expt. Lay a piece of iron or copper plate in an earthenware or glass vessel, and pour on it some diluted sulphuric acid; the metal will be violently acted upon by it and dissolved. Now touch it with a piece of zinc, and the chemical action on the first metal will be suspended, being transferred to the zinc, and until it is wholly dissolved the copper will not again be acted on.

§ 521.

Lastly, from the action of these currents, generated between e polar wires and the elements of an electrolyte, there arise eculiar movements which, from their origin, are called *electro-emical movements.* These phenomena were first observed several ears ago by Ermann, and have since been more closely investi-ated by Herschel, Pfaff, Runge, Fechner, and others. To ender these movements visible, pour the liquid that is to be lectrolyzed on some mercury, introduce the electrodes of a oltaic battery, and, according to the chemical character of the uid, the currents will be generated from the + or the — wire, ometimes from both; their course is sometimes rectilinear and t others curvilinear.

These phenomena may be observed with voltaic piles of from 10 to 20 pairs of plates, or with constant batteries of from 2 to 4 cells; with many fluids indeed, very small single batteries will be sufficient.

The following are the principal results to be noticed in performing these experiments:—

Pour some acid, *ex. gr.*, sulphuric acid, slightly diluted, on mercury, and the metal will be repelled by the + pole; but if any alkaline solution be added, it will be attracted by the same pole.

Immerse the negative wire in the quicksilver on which some alkaline solution rests, whilst the positive wire does but just touch the metal, and it will instantly collect about the — pole, and recede from the + pole. Establish the contact of the mercury again with both the poles; the same effect as before will ensue, so that there will be an alternate contraction and expansion of the metal. If an acid be used, the same pulsations occur on plunging the positive wire into the mercury, the negative wire only just touching its surface.

Runge says, that the following electrochemical motions may be induced by a simple voltaic arrangement: — Pour a concentrated solution of common salt on quicksilver, and lay very carefully a small crystal of sulphate of copper on the middle of the mercury, and in a little while the bright surface of the metal will be covered over with a film. Now touch the quicksilver, by piercing the solution that covers it with a smooth iron wire; the film will be rent asunder, then it will entirely disappear, and an electric current will be generated that will impart a rotatory motion to the crystal, which will grow less and less until it ceases to be visible.

§ 522.

The acquaintance we have now gained with the varied effects produced by the hydro-electric current will enable us to judge which will be the best adapted to serve as a measure of its strength. Fechner, who, by his admeasurements of voltaic currents, has gained so thorough and comprehensive a knowledge of the subject, gives the following estimate: —

He says that, in consequence of the unequal and inconstant degree of excitability in organised beings, the *physiological effects* of the voltaic current are by no means calculated to give us an accurate measure of its strength.

The *excitation of heat*, as shown in the incandescence of the wires, affords us a high, but by no means sufficient degree of certainty in comparing currents; and is applicable to powerful batteries, but must necessarily fail with regard to such as have but a feeble current.

The *chemical effects* of the current, and especially its decomposition of water, supplies us with an extremely accurate and invariable standard for estimating the force of the current, as regards both the quantity and intensity of the electricity. We may either compare the quantities of gas given off in the same time, or we may notice the times requisite for generating an equal quantity of gas. The voltameter, described in § 517., is an apparatus suited to this mode of measuring the current, and has been thus used, especially by Faraday: it is not, however, free from some serious defects. It cannot be applied to a simple galvanic arigement, because water is dissolved so slowly by it that the duct obtained would be imperceptible, even after the lapse of considerable time. This method is consequently limited to mpound batteries, and even when applied to them, it is attended th this inconvenience,—that all experiments conducted on this inciple require a longer time than the other methods do, to rnish us with results that can be compared. Again, in propor- n to the inconstancy of the electric current is the uncertainty d irregularity in the results obtained; and it is notorious that e stream of electricity is very variable in all the old one-fluid tteries.

There remain only the *magnetic effects* to be estimated, and in em we shall find all the requisites combined which we can de- e in an exact measure of the force of the current. The devia- n of the magnetic needle, mentioned above at § 512. as the ndamental effect, serves as a gauge by which to measure the ost powerful and the feeblest streams, by allowing the former act directly on a common deflecting needle, while the latter t on the magnet of a multiplier.

Magnets may serve in various ways to measure the force of ectric currents. Either the deviation itself is observed which e needle makes through the influence of the current upon it; the arc is measured through which a needle suspended in a oulomb's magnetic torsion balance (§ 456.) has to be turned ck, after the operation of the current upon it in order to bring to the same place again; or, lastly, the time is sought which e same needle requires when subjected to the action of a cur- nt to perform some definite number of oscillations.

There are various ways of estimating the force of a current om the angle of declination, according as the electricity passes a line or in a plane above or below the needle. If, as in acobi's Galvanometer-compass (*fig.* 188.), it is conveyed along wire just under the needle, and in the direction of the magnetic eridian, Kämtz has determined that, *the force of the current act- g on the needle is proportional to the product of the sine into the ngent of the angle of declination.*

Let c and C be the currents of two hydro-electric batteries, and a and a' the angles of declination they cause respectively in a galvanometer-compass, then

$$c : C = \sin. a \tan. a : \sin. a' \tan. a'.$$

To save the necessity of actual calculation, Pohl has constructed a table, which will be found below, for every angle from 1° to 90°, from which the proportional force of any current may be ascertained for any declination given in degrees.

TABLE XIV.

For determining the Intensity of Hydro-Electric Currents, from the Angle of Deflexion made by a Galvanometer-Compass. (Kastner's Archiv für die gesammte Naturl. III. S. 11. *von Pohl.)*

Deflexion of Needle.	Intensity of the Current.	Deflexion of Needle.	Intensity of the Current.	Deflexion of Needle.	Intensity of the Current.
1°	0·0001	31°	0·1016	61°	0·5179
2	0·0004	32	0·1087	62	0·5451
3	0·0009	33	0·1161	63	0·5740
4	0·0016	34	0·1238	64	0·6049
5	0·0025	35	0·1328	65	0·6380
6	0·0036	36	0·1402	66	0·6735
7	0·0049	37	0·1489	67	0·7119
8	0·0064	38	0·1579	68	0·7533
9	0·0081	39	0·1673	69	0·7983
10	0·0100	40	0·1770	70	0·8475
11	0·0122	41	0·1872	71	0·9014
12	0·0145	42	0·1978	72	0·9608
13	0·0170	43	0·2088	73	1·0268
14	0·0198	44	0·2202	74	1·1004
15	0·0228	45	0·2321	75	1·1833
16	0·0259	46	0·2445	76	1·2775
17	0·0293	47	0·2574	77	1·3854
18	0·0330	48	0·2709	78	1·5106
19	0·0368	49	0·2850	79	1·6577
20	0·0409	50	0·2997	80	1·8334
21	0·0452	51	0·3150	81	2·0471
22	0·0497	52	0·3313	82	2·3130
23	0·0544	53	0·3479	83	2·6536
24	0·0594	54	0·3655	84	3·1061
25	0·0647	55	0·3840	85	3·7378
26	0·0702	56	0·4035	86	4·6830
27	0·0759	57	0·4239	87	6·2551
28	0·0819	58	0·4455	88	9·6133
29	0·0882	59	0·4683	89	18·8034
30	0·0948	60	0·4924	90	infinite.

If, instead of conducting the current along a wire, it be conveyed under the needle by a strip of metal whose width is at least four times the length of the needle, the electricity flowing along this metal plate will act equally upon the needle in ever ition, for it must travel equally along the entire width of the ductor. In this case, *the force of the current is proportional to tangent of the angle of the needle's declination.* Instruments structed on this principle are called *Tangent Compasses,* and ir application depends on Weber's law, which we have just efly enunciated.

The force of those currents which deflect the needle only by ans of some contrivance for multiplying their effects cannot be imated by either of the laws given above, because, however refully the instruments may be constructed, it would be very ficult to measure accurately the different distances of the edle from the respective turns of the multiplier, and the cal-lations involved in its use would be very complicated.

An extremely simple contrivance for measuring the intensity a current by means of the angle of deflexion, consists in making galvanometer itself to revolve in the plane of the horizon out the centre of the needle. When the needle has been de-cted, turn the multiplier until, with regard to the needle, it regained its original position, and the intensity of the current ing at right angles on the needle is equal to the horizontal ce of terrestrial magnetism (§ 447.), which last force is asured by the sine of the angle through which the needle has en deflected from the magnetic meridian. But this angle is it through which the coils of the multiplier have been turned m their original position, and may be read off on a graduated le made for this purpose. Pouillet's *Sine Compass* acts on this inciple, that *the intensity of the current varies as the sine of the gle of torsion;* this instrument, when fitted up with a nonius, y be made to measure the angle of declination accurately to o minutes.

It is worthy of remark that, in all measurements from the gle of a needle's deflexion, if this does not exceed 20°, we ay assume the *intensities of the currents to be nearly as the an-lar magnitudes squared.*

The method of measurement adopted by Ohm may also be ed, the multiplier being used as a torsion balance and having needle suspended by a fine wire, which is connected with the dex of the torsion balance. When used, this index must be laced at zero, the needle too must be set at 0° in its scale; when e current acts on the needle it will deflect it a certain angle, nd in so doing will impart a corresponding torsion to the wire. ow, instead of measuring the declination itself, you are to turn ack the torsion index till the needle is restored to its original osition. *The number of degrees which the index is moved back is roportional to the intensity of the current.*

Lastly, the mode employed principally by Fechner in his measurements of observing the oscillations is equally acable to the single galvanometer, and to such as are fitted up with a multiplier. Place the needle so that it shall stand in the direction of the earth's magnetic influence, and also in the direction in which the force is emitted from the electric conductor, so that in fact these two directions may coincide. To effect this, the single conducting wire of the compass, or the coil of wire of the multiplier, must intersect the magnetic meridian at right angles, *i.e.* it must be placed in such a position that the needle suffers no perceptible deflexion whilst acted on by the current (comp. § 512.). Now make the needle to oscillate, and by § 456., *the intensities of the currents are inversely as the squares of the times of the vibrations, or the number of units of time which are required to complete the same number of vibrations.* This method possesses the substantial advantage that it is applicable to both powerful and feeble currents, that it gives very certain and much more accurate measurements than can be obtained from the generality of instruments by reading off the angle of declination, and that the magnetic intensity of the current may at the same time be compared with the force of the earth's magnetism, by observing in like manner the time of the needle's oscillation when subjected only to the action of terrestrial magnetism; on the other hand, this mode of measurement renders it indispensable that the observer should have an accurate seconds' watch or pendulum, with which to compare the oscillations of the needle.

Suppose now that the needle when acted on by the current c, performs a certain number of vibrations in ten seconds, but that when subjected to the influence of another current C, it performs the same number in five seconds; then the intensities of these two currents will be

$$\begin{aligned} c : C &= \frac{1}{10^2} : \frac{1}{5^2} \\ &= \frac{1}{100} : \frac{1}{25} \\ &= 25 : 100 \\ &= 1 : 4 \end{aligned}$$

and further, if the same needle had required 20 seconds to make the same number of oscillations when acted on only by terrestrial magnetism M, then the forces would be to each other in the following proportion:

$$\begin{aligned} M : c : C &= \frac{1}{20^2} : \frac{1}{10^2} : \frac{1}{5^2} \\ &= 25 : 100 : 400 \\ \text{Or, as} \quad & 1 : 4 : 16 \end{aligned}$$

e., if the force of the earth's magnetism is estimated as nity, that of the current c would be 4 times and that of C 6 times as great.

Magnetic measurements are also well suited to show with ccuracy the influence which the magnitude of their excited urfaces exerts on the efficiency of hydro-electric batteries.

Fechner, who has performed a vast number of experiments o ascertain this point, has determined the following, viz. that the intensity of the current increases when the area of the excited surface is increased, but in a less ratio than it. The increase in the action of a battery is nearly proportional to the increase in the exciting surface, when the fluid employed is one that has but a low conducting power, such as water; whereas, when the fluids employed are good conductors, the increased efficiency of the battery is proportionally less. The increased force of the current, attained by increasing the excited surfaces, reaches a limit, which is arrived at the sooner the less the resistance to conduction offered by the fluid, as compared with the resistance offered by the solid conductor (*i. e.* by the connecting wire).

Pohl, whose attention has been carefully directed to these investigations, lays down the following law, that *the intensities of the currents of single hydro-electric batteries, in which both electromotors present equal surfaces to the exciting fluid, are, ceteris paribus, as the biquadrate roots of the areas of the surfaces in action.*

Suppose the metal surface in one single battery to be a, that of another $m\,a$, let c be the intensity of the lesser current; then that of the greater will be

$$C = c\,\sqrt[4]{m},$$

$$\therefore\ m = \left(\frac{C}{c}\right)^4$$

Hence it appears, that if a battery be given with a certain current, considered as unity, and we desire to construct another, the intensity of whose current shall be double that of the former; the batteries being similar, the exciting surface of the latter must be $2^4 = 16$ times greater than that of the former. — I practically verified this law by comparing some Daniell's batteries, and found that to double the intensity of the current it was necessary to increase the copper surface sixteenfold. I used in each case the same wire to conduct the electricity, and I measured the intensities by the angles a galvanometer compass was deflected. I compared in like manner the intensities of a zinc and copper and of a zinc and platinum battery, the surfaces of the two metals being equal, and found that the current generated by the platinum battery was equal to what would have been produced by a copper one 16 times its size: this pretty nearly coincides with the results obtained by Jacobi, and given in § 505 of this work. For the zinc battery I used sulphuric acid diluted with 9 parts of water; for the copper, a concentrated solution of sulphate of copper; and for the platinum, nitric acid of 1·3 spec. grav., as the exciting fluids respectively. The intensities found thus were as 1 : 2, for the angles of the needle's deflexion were 34° and 46°, the corresponding intensities for which in Pohl's table are 0·1238 and 0·2445; their ratio is therefore as 1 : 1·94.—On comparing one of Hare's spiral batteries with one of Grove's, with respect to the effect of their current, the following result was obtained. The spiral battery had 372 square inches of effective copper surface; Faraday's fluid was used, and the needle of the galvanometer was deflected 36°, which, according to Pohl's table, corresponds with an intensity of 0·1402. A zinc and platinum battery, in which there were 100 square inches of the latter metal efficient, deflected the needle 46°, and consequently had an intensity of 0·2445. The same wire was used in each case to complete the circuit. According to the law given above, a platinum battery whose current should have the same intensity as that of the spiral battery would require a surface $m = \left(\frac{1402}{2445}\right)^4 = 0{\cdot}108$ times greater than it; i.e. $100 \times 0{\cdot}108 = 10\frac{4}{5}$ square inches. Now when only $10\frac{4}{5}$ square inches of the zinc and platinum battery were set in action, the compass gave a declination of precisely 36°, consequently these $10\frac{4}{5}$ inches of platinum generated a current whose intensity was exactly equal to that produced by 372 inches of copper in Hare's spiral battery. To give to both batteries an equal intensity of current, the copper surface of the latter would require to be 372 : 10·8 = 344 times greater than the platinum surface of Grove's battery.

§ 523.

At the conclusion of this important branch of the science of electricity, it is necessary that the reader should be made acquainted with the opinions of natural philosophers with regard to the primitive causes which generate galvanic or voltaic electricity. It is remarkable that the views of scientific men on this subject do not accord, notwithstanding the zealous investigations which have been made so lately into the sources of electricity, investigations too which have brought to light so much that is both new and important. The majority of the scientific world are the adherents of one or other of two theories; the older of which, known as the *theory of contact*, is based on the prine laid down by Volta ; the other, first propounded by Wol- on, is called the *chemical theory*.

The contact theory, which is held by most of the German phi- ophers, especially by Ohm, Fechner, Pfaff, Henrici, Poggen- f, Berzelius, Jacobi, and Martens, assumes that when two similar bodies are brought into actual or proximate contact an ergy is developed to which has been given the name of *electro- tive force*, but whose nature is still unknown. This electromo- e force effects the decomposition of the neutral electricities of e two touching bodies, so that a definite portion of the + elec- city accumulates in one of them, and a corresponding portion – electricity in the other; but it instantly opposes the reunion these ± electricities, and thus occasions the constant difference tension between bodies in contact. To account for the influence the chemical process on voltaic phenomena, Fechner assumes at, between the atoms of two bodies which combine chemically th each other, a process obtains similar to that which arises en two heterogeneous substances are in contact. The atoms arged with antagonist electricities are held together by their tual attraction; and this constitutes what is generally known *chemical affinity* (§ 58).

According to the *chemical theory*, which has recently been eatly extended, especially by Faraday, De la Rive, Becquerel d Schönbein, galvanic electricity is attributed to a chemical tion, and its most zealous advocate De la Rive speaks the following terms: so soon as a body comes into a seous or fluid medium and a tendency arises between the two dies to combine chemically, a disturbance ensues in the elec- cal equilibrium, and on this condition of chemical action being filled, the elements of the solid combine with the oppositely ctrified elements of the fluid. As a general rule, the body, . *gr.* the metal, which is dissolved in the process of combining, positively electrified, and the fluid which performs the part of e agent is negatively electrified: but, as in such processes a paration of the atoms takes place, that liberates the electricity hich was before held in a latent state, and which is always op- site to that which disposes the atoms to form a new combination, e result of both processes is dependent on the difference of the o influences. The intensity of the electric action thus set at ork is regulated by the difference just mentioned and also by e hindrances which oppose themselves to the re-union of the ectricities that are set free. If two heterogeneous metals are rought into contact in a medium that acts with unequal energy pon them, it will render them both electrical, that for which it as the stronger affinity being positive, and the other negative. oin several such pairs so as to form a compound hydro-electric attery, and all the rest will perform the functions of a conductor of the free electricity to each pair; the ± electricities thus meeting together in the metal, neutralize each other with respect to their quantities, the + electricity will therefore accumulate on one side and the — electricity on the other.

The advocates of each theory have been and are still employed in bringing forward proofs to establish the correctness of the views they have respectively taken, without either party being at present able to claim an undisputed victory. To these labours, however, we are in a great measure indebted for the advances that have in modern times been made in this department of science. The thorough-going supporters of the chemical theory positively deny that electricity is ever excited by contact alone, and they even go so far as to say hypothetically, that the pure metals are susceptible of oxidation. Fechner has, however, compelled them to admit that Volta's fundamental experiments are a fact too well established for us to doubt any longer whether electricity can be generated by contact only, and there are even cases of hydro-electric combinations in which electrical action obtains agreeably to the assumptions of the contact theory, without any chemical action whatever of the fluids on the electromotors (1): nay, frequently the contact of the metals is the cause that this action, originally a purely chemical one, is suspended and an opposite one commences (2). Many partisans of Volta's theory are decidedly of opinion, that chemical action is never the primitive cause of electrical excitement, although they do not call in question the possibility of chemical influences being frequently the immediate, but not the original, cause by which electricity is generated (3): some who hold this theory even concede that chemical action may increase the intensity of the electrical process, when its excitation coincides with that of contact. After all, the main difficulty will be to determine what share chemical influence really has in exciting electrical action, because without contact scarcely any chemical change can transpire, and also because the effect produced must depend on so many secondary circumstances, such as the degree of concentration of the solutions, the temperature of the fluid, &c.

1.) Pfaff adduces the following *experimentum crucis* to show, that without any chemical action whatever by the fluids on the electromotors immersed in them, a powerful electrical excitement is generated solely by the contact of the latter.

First Expt. Take a zinc and platinum battery, and use a neutral solution of sulphate of zinc as the fluid which is to act on the zinc, and for the platinum, as usual, nitric acid; then neither of these fluids will exert any chemical influence on the metals immersed in them, according to the laws of chemical affinity, and yet a current of electricity will be generated as powerful or nearly as powerful on con necting the wires as if sulphuric acid had been used with the zinc.

2.) Berzelius gives the following as a strong proof that the excitation of electricity by the contact of heterogeneous bodies is altogether independent of the chemical influences acting on them, and that the excitation of electricity regulates the chemical action, nay, even reverses it sometimes.

Second Expt.

Fig. 196.

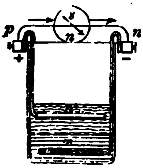

Fig. 196. represents a simple battery of two metals and two liquids; Z is an amalgamated zinc plate near the bottom of the cylindrical glass vessel, and C is a copper-plate of equal size, parallel to it. A bent strip of metal goes from both and being bent over the rim of the glass supports the two plates and performs the office of a conductor to them; its ends *n* and *p* are provided with binding screws, and the whole of the strip is coated with a varnish by which it is protected against any chemical action. A perfectly saturated solution of sulphate of zinc is poured on the bottom of the glass till it reaches half way between the plates of zinc and copper; on the top of this pour some common nitric acid through a fine glass funnel whose tube is slightly curved at the end, so that the acid may lie on the much heavier solution of zinc without forming a mixture with it; continue to add acid till it stands about half an inch above the copper-plate.

Until the circuit is completed by connecting the wires, the chemical forces alone are in operation, and in accordance with the laws of affinity, the copper is rapidly dissolved by the acid, whereas on the zinc no action takes place or can take place. Now if the chemical theory were correct in assuming that the oxydation of one of the metals controlled the electrical relations of the battery, then the copper, as being the metal which is chemically affected, must needs be positively electrified and the zinc negatively. But on completing the circuit the solution of the copper ceases instantly, the green tint disappears gradually from the solution, and the reduction of the copper held in solution begins on the copper-plate, whilst a cloudy appearance rises about the zinc caused by the formation of the oxide of zinc, and a galvanometer compass forming a part of the electric circuit would shew that the current had taken the direction which accords with the principles of the contact theory.

3.) To prove the generation of electric forces by means of a chemical combination, Becquerel adduces the combination of an acid with an alkali.

Third Expt. Pour a little nitric acid into a platinum saucer, which is connected with one wire of a galvanometer: connect the other wire with a piece of platinum wire whose free end is bent into a hook, about which twist some asbestos or cotton, saturated with a solution of potash or soda. At the moment when this alkali is dipped in the acid contained in the platinum saucer, the needle of the galvanometer shows the existence of a current passing from the alkali to the acid.

Explaining this on the principles of the chemical theory, the current is generated by the chemical action of the fluids one upon the other; by the contact theory it would be attributed to the electromotive action of the different fluids on the platinum, or the whole combination would be regarded as a battery of one homogeneous metal in two heterogeneous fluids. (§ 505.)

It is by no means improbable that neither of the theories, pushed to an extreme, fully coincides with the truth; and some philosophers, amongst whom are to be reckoned Jacobi, Buff, Baumgartner, Von Ettinghausen, and Pohl have constructed a theory which holds a middle course between the two we have already explained. These views merit a place in this part of our work, as in them what is favourable to each of the other hypotheses is fused together in such sort that the various phenomena are more satisfactorily accounted for than by either of the original theories.

It has long been held that those forces which lie at the basis of adhesion, and those which cause chemical affinity, are not essentially different: some philosophers have even attempted to estimate the degrees of affinity by the amount of adhesion. It is therefore by no means unscientific to regard chemical attraction as merely a more powerful adhesive force. Prechtl has indeed tried to prove the connexion between the adhesion of metals and their electrical difference, *i. e.* their relative position with respect to tension (§ 502.); Becquerel has shown that electricity is generated by capillary attraction, which is known to depend on adhesion and cohesion. Again, we know from Girard's experiments, as well as from the theory of capillary tubes, that adhesion causes a variation in the density of fluids where they are bounded by solids. Resting, then, on these facts, we believe that, *when electricity is generated in any voltaic arrangement, it results from a molecular change brought about in the touching bodies by the adhesive force which subsists between them.* This change is sometimes merely in the density of the touching bodies, it is often confined to the strata contiguous to their points of contact, but with a force of considerable intensity, and under favourable circumstances, it *extends to* the chemical nature of the bodies. This theory pos-

dvantage that no new power need be assumed to exist
ie contact theory requires us to allow the existence of
motive force); and it also accounts for the production
y apart from any chemical action. It has this in com-
ie chemical hypothesis; that it deduces the phenomena
e battery from the molecular forces; that it considers
ot merely as a conductor of the electricity, but as
its production, and that the elements of the battery,
sical changes they undergo, are the actual sources of
ity; that their contact renders this change possible;
efore is the occasion, and not the generating cause by
electricity is produced. In these points it approxi-
e nearly to the chemical than to the contact theory,
poses that electricity may be developed without any
nge in the bodies: indeed the chemical hypothesis is
ecial case of the molecular. The simultaneous com-
of chemical action with the development of electricity,
umstance that the chemical intensity of a simple vol-
ement increases and decreases as the chemical action
id conductor and on the elements of the battery is
less, fully accords with the statements of this theory.
hence, that the electrical and molecular force are one
ne, and that the latter appears as electricity whenever
om one mode of operation into the other, as, *ex: gr.*,
ses to hold together the elements of the water, and so
e zinc. Schönbein's most recent hypothesis of chemi-
cies does not differ essentially from the views just

RICAL PHENOMENA RESULTING FROM THE CHEMICAL HAT ATTENDS THE CHANGE IN THE AGGREGATE FORM S; THOSE WHICH RESULT FROM THEIR SEPARATION BY CAL MEANS; AND THOSE WHICH ARE CAUSED BY THE SION OF BODIES.

§ 524.

order to those electrical phenomena which are pro-
riction, and those which are generated by contact, we
such as attend the chemical action of bodies one on
e change in their aggregate forms, the destruction of
on by mechanically separating their particles, and by
In all the instances just specified, a change takes place
cular condition of the bodies, partly in the interior of
s, partly at their touching surfaces, and according to

the opinions of some philosophers (see § 500. and 528.), this change may in these instances also be regarded as the universal cause by which electrical equilibrium is disturbed.

The condition of electrical neutrality is upset in chemical combinations and decompositions of many bodies, as may be proved indisputably by connecting the bodies, thus combining or decomposing, with the wires of a galvanometer, or with the conductor of a sensitive electrometer. Now whether the current indicated by the galvanometer, or the electrical tension marked by the electrometer, be owing, according to the contact theory, to the bodies touching each other, or, according to the chemical theory, to the chemical action of the substances on each other, the adherents of both theories will allow that a disturbance of the electrical equilibrium, as shown by the galvanometer or electrometer, actually exists; now, as by the electro-chemical system (§ 516.), every chemical combination depends on the union of electrical opposites, the state of electrical equilibrium will necessarily be destroyed both in chemical combinations and decompositions. The following experiments are given as illustrations of the excitement of electricity attending both these kinds of chemical operations: —

> *First Expt. Electrical excitement with chemical combinations.* — Nobili gives the following experiment to prove that electrical excitement is the result of chemical combination; Fechner repeated the experiment with some variation: —
>
> Fill two small glasses, A and B, with a solution of nitrate of potassium into which conduct the wires of a galvanometer whose ends are armed with plates of platinum. A third glass, C, containing dilute nitric acid, is then placed near the other two, with which it is connected by means of two threads of asbestos or cotton, dipped in the dilute nitric acid. Now twist one of these conductors about a small piece of caustic potash before using it to establish the connection of the battery, and a chemical action will immediately commence of these two substances, and at the same time a deflexion of the galvanometer needle, which shows that the current passes from the potash to the nitric acid. Similar deflexions ensue with other chemical combinations of the same kind, as well as with those in which the substances that have an affinity for each other do not acquire a conducting power until they have been fused or melted.
>
> In the arrangement just described, it is to be noticed that the platinum plates connected with the galvanometer are immersed in the same fluid which is contained in the glasses A and B, and that consequently the electric current is not generated by the contact of the metal with heterogeneous fluids, but the electrical equilibrium is disturbed in the glass

C at the very instant when the caustic potash comes in contact with the nitric acid.

A much more powerful current is obtained by leaving out the middle glass C, pouring nitric acid into A and a solution of caustic potash into B: the homogeneous platinum plates are then to be plunged in the heterogeneous fluids, and A and B are to be connected in the same way as before. By this arrangement we obtain a Becquerel's battery (§ 505. 2.) A current is generated by the contact of the platinum with these two dissimilar fluids, similar to that which was produced by the chemical action of the caustic potash with the nitric acid. From the difference between the intensities of the currents, we see at once what share is to be attributed to each of the exciting causes in the case where their operations are combined.

Second Expt. Immerse simultaneously two homogeneous strips of platinum, connected with the wires of a galvanometer, in a glass containing nitric acid. The platinum plates are then in contact with the same fluid, and that one which exerts no chemical influence on them; the needle of the galvanometer will therefore be at rest. Now let fall one drop of hydrochloric acid on one of the platinum plates, and instantly the needle will be deflected, showing the passage of an electric current from one plate to the other. The nitro-muriatic acid formed by the drop of muriatic acid acts chemically on the platinum in contact with it. This instance is, however, one of those in which it is difficult to determine what share chemical action really has in eliciting the electric current. The adherents of the chemical theory consider the chemical action; while the partizans of the other hypothesis regard the contact of the homogeneous metal with the heterogeneous fluids as the sole cause by which the current is excited. Probably the fact is, that it is owing to the two agencies combined.

Third Expt. Electricity produced by Combustion. — According to Pouillet's experiments, when charcoal is burned it is rendered negative, and the carbonic acid which is formed is positive. He placed a small cylindrical piece of good conducting charcoal, having a very smooth bottom, on a plate of brass, which was connected with the condenser of an electrometer, and then ignited its upper end. The combustion was supported and accelerated by blasts of common air, or, still better, by a supply of oxygen. When the lower plate of the condenser was connected with the ground, the instrument appeared in a few seconds to become charged with — electricity. When the charcoal was set on a metal plate connected with the ground, and, during the process of combustion, held so beneath the brass plate of the condenser that the carbonic acid which was generated was accumulated on it, the condenser was charged with positive electricity. Dellmann also noticed the liberation of — electricity attending the combustion of charcoal, and Pfaff confirms it, but denies that the least trace of + electricity is to be found in the carbonic acid which is given off. Several philosophers have asserted that analogous traces of the liberation of electricity attend the combustion of some, but not of all, combustible bodies.

Fourth Expt. Electricity produced by Chemical Decomposition. — The experiments of Dr. Böttger may be adduced as examples: — Connect a platinum cup with the condenser or with the conductor of a delicate electrometer by means of a wire terminating in a ring. On this ring lay the cup, put in it a few grains of citrate or oxalate of silver, and apply the heat of a spirit-lamp until the salt is dissolved. Remove the lamp, and the electrometer shows — electricity to have been liberated; and in the platinum cup some very fine and minute particles of metallic silver will be found.

Fifth Expt. Lay a piece of blotting paper moistened with water on a metal plate connected with the condenser, and on it place a few crystals of nitrate of copper wrapped up in tinfoil. Pierce a few holes in the tinfoil with a pin. Moisten the whole with a little weak spirits of wine, and the salt will soon begin to decompose; and at the moment when sparks become visible, and nitrous vapour rises, the condenser is charged with — electricity.

Sixth Expt. On the conducting plate of any sensitive electroscope (*ex. gr.*, either a Becquerel's, *fig.* 157., or an Oersted's, *fig.* 156.), lay a zinc cup, and pour into it dilute muriatic or sulphuric acid, and the electroscope will show, after the hydrogen has been given off and a chemical solution of the metal has been formed, that — electricity has been liberated. A similar phenomenon is observable if, as in the fourth experiment, clean iron filings are placed in the platinum cup, and either muriatic or sulphuric acid poured on them.

§ 525.

Electrical phenomena have been seen to attend a change in the aggregate form of many bodies, especially in the solidification of such as are in a state of fusion, and in the freezing of water. The sparks that become visible during the crystallization of cerin salts, and the attendant electroscopic effects, seem rather to sult from a separation taking place among the crystals after eir formation, than to be a consequence of crystallization itself.

First Expt. Melt some sulphur in a glass, and cool it on any good conductor; on taking it out of the glass it will be negatively electrical, and the glass will be positive. Perform the same experiment in a metal cup: the latter will be negatively electrified, and the sulphur positively. Similar phenomena may be observed in the solidifying of chocolate.

It cannot be positively asserted that the electrical phenomena just noticed are absolutely consequences of the change of aggregation in the mass of the body. Some philosophers are of opinion that they are properly owing to the friction which is generated when the solid bodies are separated from the vessels containing them. If this supposition is correct, these phenomena come rather in that category of which we shall have to speak in the next section.

Second Expt. Water frozen quickly at a very low temperature (22° below zero, Fahr.) in a glass coated outside like a Leyden jar, according to Grotthuss, is positively electrical; if melted rapidly at a high temperature it shows — electricity.

Undoubted proofs are still wanting to show whether electricity is liberated by the change of liquids into steam or by the condensation of the latter. Pouillet is persuaded that from numerous experiments, he has found the escape of steam from alkaline water accompanied with positive, and that from acidulated water with negative, electricity; Pfaff, who repeated the experiments, doubts the fact. As the results, as well as those which attend the combustion of bodies, are of considerable importance on account of the conclusions that have been drawn from them respecting the electrical phenomena that arise in the atmosphere, and especially since some doubt is felt as to their correctness, it is much to be wished that the same experiments should be repeated, and careful reference be made to all circumstances affecting the results.

That a considerable quantity of electricity is liberated when high-pressure steam escapes into the atmosphere was discovered accidentally in 1841, when it was first noticed in the boiler of a locomotive engine. Armstrong, who rigorously investigated the phenomenon, found no trace of sensible electricity in the steam contained in the boiler; and that none was developed till the steam reached the open air, when it was invariably positive; that the production of electricity was proportional to the amount of steam generated, and that its intensity increased with the tension of the steam; lastly, that not only were sparks emitted by it, but it gave shocks like those obtained from a Leyden jar. Pfaff performed the same experiments with a Papin's digester, and confirmed in general the correctness of Armstrong's inferences; he obtained precisely similar results when he used distilled, alkaline, and acidulated water. His opinion is that the electricity is generated by the pressure of the steam on the water; he therefore considers that these phenomena may properly be ranged under the head of electrical phenomena produced by pressure; Armstrong, on the contrary, thought at first that this electricity arose from the condensation of the steam, but he has since given it as his opinion that the electricity is generated when the steam is exposed to friction: he does not, however, believe that this friction is the exclusive cause of its production. His investigations may involve important consequences which have not yet been perceived, for in high-pressure steam we have so remarkably fertile a source of electricity, as greatly exceeds the best electrical machines.

A short description of Armstrong's *Hydro-Electric Machine* may not be out of place here. It consists of a boiler of wrought iron of cylindrical form 3½ ft. long and 1½ ft. in diameter; its ends are rounded off into hemispheres, and with its frame and grate for the firing, it is insulated by means of glass legs. When the steam is allowed to escape through certain cocks constructed for that purpose, the pressure being 70 lb. to the square inch, an effect is obtained 7 times greater than from a good electrical machine with a plate 3 ft. in diameter; the comparison was made in the following manner. A Lane's jar (§ 487. *fig.* 162.) with 198 sq. in. of coated surface, was used to measure the electricity generated by both the machines. When the balls were held ½ an inch apart, and the plate was turned round 70 times in a minute, 29 discharges were obtained from this electrometer; on connecting it with the insulated boiler 220 discharges were obtained in the minute. Armstrong considered that each single ray of steam as it issued from the cock into the air, gave out as much electricity as a good electrical machine of ordinary size; and as a boiler capable of generating steam equal to that of a locomotive engine could discharge 100 such rays, we may form some idea of the prodigious development of electricity that may be effected by means of steam.

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* NOTE. — The subject has been investigated by Faraday, who thus expresses the conclusion at which he arrived: — "The cause of the evolution of electricity by the liberation of confined steam is not evaporation; and further, being, I believe, friction, it has no effect in producing, and is not connected with the general electricity of the atmosphere: also, that as far as I have been able to proceed, pure gases, *i. e.* gases not mingled with solid or liquid particles, do not excite electricity by friction against solid or liquid substances."

§ 536.

Electrical phenomena have been noticed in many bodies, especially in those of crystalline form, when a sudden disruption of heir internal structure takes place. When by mechanical or ther means their cohesion is overcome, sparks are seen, and the ivided portions are in a state of opposite electrical tension.

The following experiments may serve as illustrations:

First Expt. Becquerel observed that when a small cleft was made in a lamina of mica, and a stick of sealing-wax was fastened to the portions of the crystal thus prepared for splitting, on tearing them asunder a luminous appearance was visible in the dark, and each of the fragments after rupture was oppositely electrified. The like obtains with other crystallized minerals if treated in the same manner. We may mention gypsum, calcareous spar, &c.; the same phenomenon may be noticed in tearing a common playing-card.

Second Expt. Dr. R. Böttger mentions the following electrical phenomena as observed by him in a salt crystallized by fusion. Connect a platinum dish or a small crucible by means of a bent wire, with the conductor of a sensitive electroscope. In this metal vessel place some crystals of sulphate of copper and potash, which are to be heated by applying a spirit lamp under the dish until the crystals have parted with their water of crystallization, and are reduced to a perfectly liquid state. When the whole is in this state of fusion remove the lamp, and within a few seconds the entire mass will crystallize, but without any trace of free electricity; so soon, however, as the mass has acquired a solid crystalline structure, it begins to contract and gradually to rend asunder, this process being attended by an audible crackling noise; the electroscope distinctly shows + electricity to be liberated every time that the contraction of the mass produces a rupture in the individual particles. In proportion as the mass becomes gradually reduced to a pulverized condition, the electrical phenomena disappear; the experiment may however be repeated at pleasure by fusing the salt in the manner described already. Dr. Böttger considers this as a convincing proof that electricity and light are evolved, not so much at the moment when the crystals are formed, but rather when a crystal already formed touches or destroys another; he is also of opinion that the bright sparks which, according to Rose's observations, are to be seen in gradually cooling a solution of white arsenic, are derived from a like source.

Lastly, we must reckon under the same class all those elec-

This property in tourmaline was known to Æpinus; it was subsequently found that it belonged to other and even to artificial crystals. The philosophers who have done the most to extend this department of science are, Brewster, Haüy, Ermann, Becquerel, Forbes, Hankel, P. Riess, and G. Rose. In all bodies of this class the tension is of very low intensity; so that up to the present time no use has been made of this source of electricity.

In good conductors a state of thermo-electrical tension is induced only by insulating them, and applying a strong heat to one end, which becomes positively electrified while the opposite extremity is negatively electrified.

Second Expt. Connect a platinum wire with the plate of a condensing electroscope, and let the free end terminate in a helix. Now raise the spiral to a red heat, hold the stand of the condenser in your hand, and form a conductor of moistened paper to the spiral; the latter will be charged with positive electricity, and the plate of the condenser with negative.

§ 529.

Heat, or cool, one end of any good conductor, as a wire or strip of metal; on hinging together its two ends, which stand at unequal temperatures, a *thermo-electric current* will be generated. The same result will follow at any part of an electric circuit where the mass of the body is at all modified, as, for instance, where a difference in the thickness or in the density of the substance causes a variation in the temperature. In both cases an opportunity is offered by the local influence of the heat for the ± electricities, which had been held asunder to re-unite in the path presented to them by the conductor. Had no such variation existed in the interior of the conductor, that is to say, had it been perfectly homogeneous throughout, as in a wire of exactly equal dimensions from end to end, then no electric current would have been generated From this and similar circumstances Becquerel thinks we are warranted in inferring that a change in temperature is not the sole requisite for the production of thermo-electric currents, but that other causes must be in operation by which the distribution of heat is hindered from being uniform, so that it moves more rapidly on one side than on the other of the hot or cold spot.

The intensity of the current varies according to the nature of the conductor used; as a general rule, it is greater the greater the difference in the temperature, and as this diminishes again the intensity becomes less.

With regard to the degree in which the metals become electri- through inequality in their temperature, Yelin gives the fol- wing list, in which he places first that which is most powerfully cited, and the last that which is least so: bismuth, antimony, nc, silver, platinum, copper, brass, gold, tin, lead: Emmett and obili have arranged the metals in two groups, according to the rection the current takes; in the one class placing those in hich the positive current is propagated in the same direction as e heat, in other words, in which it goes from the hot to the ld part of the metal; in the other group those in which the rrents of heat and positive electricity run in opposite directions. mmett places platinum, gold, silver, copper, and nickel in the st, and tin, lead, zinc, iron, brass, arsenic, antimony, and bis- uth in the second. Nobili reckons bismuth, platinum, gold, ver, tin, brass, lead, and copper to belong to the first class, and nc, antimony, and iron to the second. From these two lists it readily seen that the negative metals which are not easily ydized by heat give out + electricity, and the positive metals hich soon oxydize give out − electricity. Nobili says that if o dry cylinders of clay be connected by means of a wire, and e end of one be very much heated, and then placed in contact ith that of the other, a current of electricity will immediately oceed from the hot to the cold cylinder.

To prove the production and existence of thermo-electric currents, it is necessary to make use of a galvanometer (§ 512.). Since, however, they possess but a small intensity, the resistance to conduction in the instrument itself should not be considerable. This is effected by making but few coils, and employing pretty stout copper wire, about $\frac{1}{30}$th of an inch in thickness; or Fechner recommends a strip of copper instead of the coils of wire, and an astatic needle having the freest possible motion, such as is used in Nobili's galvanometer. (§ 512., *fig.* 190.)

Fig. 197.

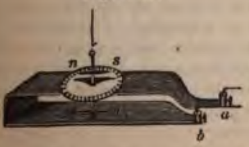


Fig. 197. represents a strip of copper thus substituted for the usual coils of wire, the width of the metal being equal to the length of the needle. The ends are shown in the diagram to taper off, and are bent so that they can be brought in a horizontal position near to each other; they are furnished with binding-screws, *a* and *b*, to secure the ends of the conductor in which it is desired to generate a thermo-electric current. In the upper plate is a slit through which the lower needle, *n s*, suspended by a thread, can be [illegible] and antimony [illegible] with regard to [illegible] of the succeeding [illegible] if joined with [illegible] positive [illegible] these [illegible] temperature is lowered. Th [illegible] same [illegible] intensity of [illegible] metals are adjacent in the [illegible] the two extremes, form t [illegible] batteries so sensitive that by [illegible] with the naked hand th [illegible] temperature of the metals being but [illegible] Brass which stands pretty near [illegible] combined with bismuth or antimon [illegible] of great power. When combine [illegible] electro-positive element; and with ant [illegible] negative. Further, it has been ascertai [illegible] intensity of many par [illegible] to the difference in the temperature of [illegible] with others this proportion is confined with [illegible] range or even has no existence whatever [illegible] which obtains between the thermo-elect [illegible] consists in this, that in such batteries [illegible] than two heterogeneous metals, the inte [illegible] the same as would have been obtained by [illegible] negative and most positive members. It [illegible] that this relative position of the met [illegible] only when they are chemically pure [illegible] their position is thereby materially [illegible] presumed that we are furnished wi [illegible] metals.

[illegible] Cumming have also noticed that [illegible] other conductors of electricity f [illegible] which is especially of import [illegible] drawn from it as to the existence [illegible] this subject will be m

A very convenient [illegible] structing these simple batteries is represented [illegible] is a bar of bismuth or [illegible] 4 or 5 inches long, from [illegible] wide, and about 1 or [illegible] ness. To it is soldered [illegible] or brass, of equal w [illegible] bent at right a [illegible] such a manner that [illegible] tween the parallel meta an inch. As has been remarked above, the most powerful simple battery is obtained by combining antimony and bismuth in this manner. In the middle of the lower plate is an upright piece of wire, finely pointed, and carrying a sensitive needle, *n s*, which has a graduated circle immediately beneath, on which the angle of its deflexion may be read off.

The following experiments can be performed by means of such a thermo battery as we have just described, consisting of bismuth and brass, antimony and brass, or antimony and bismuth.

First Expt. with a bismuth and brass battery. Place the apparatus in such a position that the longer direction of the battery may coincide with the magnetic meridian, and have the same polar position as the needle. Heat the southern joint at *a* by holding under it the flame of a spirit lamp, and the north pole of the magnet will begin to turn towards the west, its deviation increasing as the temperature rises. Hence it follows that (by § 512.) the current proceeds from *b* to *a*, *i.e.* from the cold to the heated end.

Second Expt., with a battery of antimony and brass.— Treat this in the same manner as the preceding, and the north pole will be deflected eastwards; hence the current goes from *a* to *b*, or from the hot to the cold part of the metal.

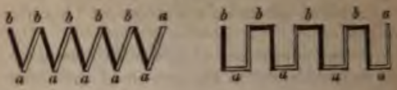
Third Expt., with a battery of antimony and bismuth. — The deviation in this case will be similar to that in the preceding, only that it will be much greater, the joint *a* being heated as before.

Cool *a* by the method given in the fourth experiment of the preceding paragraph, and the needle will be deflected in an opposite direction; the intensity of the current will be doubled by simultaneously heating *a* and cooling *b*. As a general rule, the sensibility of single thermo-electric batteries may be increased by using a double astatic needle, as in Fechner's thermo-galvanometer, *fig.* 197.

§ 531.

Compound thermo-batteries, or *thermo-electric piles*, may be constructed by combining a number of single ones on the same principle as voltaic piles or hydro-electric batteries are formed. Connect the single thermo-electric batteries by soldering together the two heterogeneous metals in pairs, so that the poles of the pile may end in two heterogeneous metals. Heat simultaneously all the junctions on one side of the pile, and cool all on the other, so that a heated point follows a cold one throughout; and the currents emanating from the poles will display an intensity p portional to the number of pairs. *Fig.* 200. is a scheme of s

Fig. 200.



a combination, the dark lines representing the one metal, an faint lines the other. Let *a* be the junctions to be heated, those to be cooled, or *vice versâ*. These thermo-piles have variously constructed, according to the purpose to which are applied, differing in form, dimensions, and the metals us electromotors. Bismuth and antimony are the metals most rally employed, and the piles made of them are the most effi and sensitive, but they cannot be used at high temperatures the heat to which the battery is to be exposed is great, plat and iron should be used. The metals are commonly in the of four-sided prismatic bars, a few inches long, frequently one inch in length, and a few lines in thickness and breadth

These thermo-electric piles produce effects precisely simi those brought about by the hydro-electric piles; *i. e.* if the sist of a sufficient number of pairs of adequate dimensions produce the same phenomena of light and heat, they exci same physiological sensations, and exert the same chemical ence, but in a lower degree; because of the resistance to co tion that has to be overcome, which resistance prevents th rents generated by these piles, even when they consist of pairs, possessing an intensity equal to that of currents ema from hydro-electric batteries.

Munke describes one of these piles which he ha structed, the current of which produces all the effects above: it consists of 81 pairs of antimony and bi bars, 27 lines long. 5 wide, and 4 thick. The pairs o are arranged in 9 rows of 9 pairs each, which, with t metal connecting pieces, give 90 junctions on each sur the pile. The under side stands in a tin vessel full of containing ice and snow, while a copper plate of b charcoal is laid on the upper side.

§ 532.

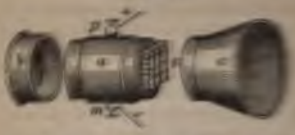
Our theoretical views and their practical application have de-
ed considerable advantage from our increased knowledge of the
ure and properties of thermo-electric currents. Undoubtedly
most important benefit, and that of which the most extensive
has yet been made, is the application of the thermo-electric
rrent to measure temperatures in cases where other instruments
re not sufficiently delicate, or where the temperatures were so
tremely high or so very low that our ordinary pyrometers and
ermometers could not be relied on; or, lastly, to measure the
gree of heat in places where other kinds of apparatus could not
used. The strength of the current generated by the heat in a
ermo-battery measures its temperature; the intensity of the
rrent being estimated, as in hydro-electric batteries, by the
flexion of a magnetic needle. An apparatus of this kind is
rmed a *magneto thermometer*.

As yet it has been most extensively used to determine very
inute differences of temperature. The *magnetic differential*
ermometer, constructed for this purpose by Nobili, consists of a
le of bismuth and antimony, whose poles are connected with a
licate thermo-galvanometer. When in use the source of heat
be tested is allowed to operate on one half of the junctions,
hile the other half are kept at as low a temperature as possible.
he delicacy of an apparatus of this kind is such that, according
Nobili's observations and comparisons, it is capable of mea-
uring by the deflexion of the needle a difference of temperature
f $\frac{1}{3300}$th of a degree. By the aid of such a delicate instrument,
elloni was enabled to carry on his beautiful and important in-
estigations into the relations of radiant heat with the greatest
ccuracy, as well as to confirm them by experiments that admit-
ed of no doubt (see § 384—389.). Von Wrede used the same
eans for determining the velocity of radiant heat (see § 381.).

The thermo-electric piles recently constructed by Nobili and Melloni are of various forms, according to the use to which they are to be applied. In that which Nobili calls "pila a scatola," the prisms of bismuth and antimony are so arranged that each half of the junctions stands near the other in a square. All the pairs are enclosed in a brass box of cylindrical shape, in which they are insulated, with respect both to the box and to one another, by having the interstices filled up with gypsum, wax, or resin. The two poles of the pile end on the outside of the cylinder in two binding-screws, by which they may be connected with the thermo-galvanometer. Both ends of the pile can be closed by a lid

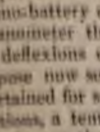
which shuts on over the cylinder. These piles a
chiefly for investigations into the phenomena of [illegible]
which reason their junctions are left polished, an
crease their sensibility, the lid is [illegible]
be filled with snow. — *Fig.* 201. represents the

Fig. 201.



a is the box
contains the
one set of junc
visible; p and n
two binding-scr
nected with the
wires go from
the galvanometer
c are the two lid
up the box with. If the pile is intended for exp
on radiation, the junctions must terminate in sharp
points, blackened to increase their absorption of hea
are placed either side by side in a square, or they
straight line — the "pila a pettine," to investigate t
mena of diffraction; or they are ranged within a ci
the *rays* of a star; see *fig.* 202., where the rays
act on the junctions inside. This fo
adapted for the rays of heat concentr
convex lens. In all these piles the
the junctions on which the rays are
to act is furnished with a conical or
reflector, widening outwards, as is sh
fig. 201., in which the rays of heat m
ceived, while the other side is secure
their influence by being closed with

Fig. 202.



For the first idea of a *magnetic pyrometer* we are in
Becquerel. This distinguished philosopher made
thermo-battery of copper and iron, which he connect
galvanometer that he regulated in such a manner as t
the deflexions of the needle in values of the electric
Suppose now some definite intensity of the current
ascertained for some particular high temperature of o
junctions, a temperature, however, that could be appre
the common thermometer, while the other two are k
freezing-point; if any additional heat beyond the ran
thermometer be applied to that junction, a still further
of the galvanometer would ensue, and this higher te
would be immediately given by the deflexion in degre
particular thermometric scale which had been used in va
original deflexion. Pouillet's magnetic pyrometer ac
same principle; it consists of a gun-barrel, to which are
two platinum wires that are connected with a thermo

le by coiling a strip of very thin copper some twenty-

The construction of this galvanometer in other points
that of the sine compass (§ 522.); and, by a formula
ives, we may calculate from the angle of the needle's
what is the temperature of the junction exposed to the
means of such an instrument the fusion-point of most
als has been determined (§ 401.) Pouillet also used
-electric battery for determining the maximum degree
He endeavoured to ascertain the temperature at which
freezes and sulphuric æther combined with solid car-
begins to solidify. He used a battery of bismuth and
d found the degrees of cold shewn by it to agree
th those given by an air-pyrometer and a spirit of wine
er with which he compared them; he considered,
that the indications of this apparatus are proportional
rences of the temperature as low as − 100° centigrade
Fahr., or 180° below the freezing point.

d use to which these thermopiles have been applied is
the temperature of places; they have been employed
ng the temperature of the sea, and that of the earth's
arious depths below the surface, as also that of the
at different elevations. The simple batteries as yet
e purpose consist of an iron and copper wire, whose
ldered together; the length will vary according to the
f the point whose temperature is to be investigated.
junctions must be at this place, and the other at the
ere the observations are made. A thermo-galvano-
nnected with the battery, and shows by the deflexion
lle what is the difference in the temperatures of the
s. Now to measure this, Peltier immersed the junc-
place of observation in some fluid whose temperature
r lowered, as the case might be, till the galvanometer
d at zero, when the temperature of both the junctions
ual. A thermometer standing in the fluid showed the
point, and at the same time also that at the more
ction. These measurements will not always give
ccurate results, especially when the difference between
atures is small; and if the length of wire to be tra-
he current is considerable, its intensity will sometimes
ate to overcome the resistance to conduction and
nagnetic needle.

erving of remark that by means of a thermo-electrical
such in principle as we have just described, but of
lified somewhat in form, Becquerel, Brechet, and Du-
ve succeeded in obtaining important estimates of the
f cold-blooded animals and living vegetables.

lication of thermo-batteries to this use led Peltier at ngth to the important discovery, that a hydro-electric current, n its passage through a single thermo-battery, is capable of enerating either heat or cold at its junctions; the former, when s direction is opposite to that of the thermo-electric current hich is generated by raising the temperature of the junctions; e latter, when its direction is opposite to that of the current roduced by cooling the same points. The apparatus best dapted for testing the difference of temperature caused by the ydro-electric current is *Peltier's Thermo-electric Cross*, which onsists of two strips of different metals, as, e.g., antimony and ismuth, laid one over the other in the form of a cross, and soldered together at the point of intersection. Two heterogeneous etal ends of such a cross are connected with the poles of a ingle hydro-electric battery, and the other two with a thermo-galvanometer. As the stream flows through the junctions the eedle of the galvanometer is deflected, from which we infer hether these points have been heated or cooled. The voltaic urrent may be allowed to act alone for some minutes; then suspend it and connect both ends of the cross with the galvanometer; he same result is obtained. If the cross be made of antimony nd bismuth, the junctions are heated when the current proceeds rom the former metal to the latter; on the contrary, if they are ooled it goes in the opposite direction. Corresponding results ve been obtained with other thermo-electric combinations, and s a general rule, it seems that heat is elicited when the positive urrent passes from a bad to a good conductor; that cold is produced when these circumstances are reversed. Von Lenz so owered the temperature of a junction in an antimony and bismuth battery by the voltaic current as to freeze water.

§ 533.

[illegible] mediately a cause by which the electrical equilibrium
[illegible] disturbed, if it produce local heat, especially in those
[illegible] heterogeneous substances touch. This effect of sun-
[illegible] explained by attributing it to the thermal influence
[illegible] (§ 425.); but the inferences that we seem to
[illegible] ing as to the warming of the earth's surface
[illegible] special importance. Since the crust of our
[illegible] as a battery of heterogeneous matter,
[illegible] electric currents have for the most part the
[illegible] which its heat advances, it has hence been
[illegible] rotation of the earth from west to east,
[illegible] the sun's rays goes on in an opposite
[illegible] west, and that to this the electric
[illegible] for they hold on their course unin-

same direction on and within the earth's crust,
the equator and its parallels. This theory,
nost modern philosophers, was first broached

ance of this theory induced several scientific
:e experiments to determine the actual exist-
urrents. In the year 1830, Fox performed a
iments in the mines of Cornwall, by connect-
t stations in the same vein with the wires of a
He thus ascertained the existence of elec-
of different degrees of intensity within the
ection in some cases running from E. to W.,
W. to E., and when the stations were at un-
below the surface, the electric current was
ıwards; Pentherick and Bennett verified this
ı in their experiments in other mines. Pro-
:xperiments, which he carried on in 1838 and
ınines of Saxony led to similar results, inas-
ound the direction of the currents to depend
hical situation of the place, and on the depth
ıelow the surface.

cquerel has since made us acquainted with
ical influence of light. From a series of
genious experiments, this philosopher found
:al rays (§ 358.) of the sun and of artificial
ch an influence on plates of metal immersed
ey can decompose, as to cause electrical phe-
could not be produced by means of heat
the plates thus exposed to these rays became
rified. The fluid must be one chemically acted
Subsequent experiments have shown that the
ı of light is not the sole exciting cause of
but that the radiation of the metal exerts a
nce on this phenomenon. That light alone,
emical action, might produce this effect, can
e following experiment. A vessel was divided
by means of a capillary partition, and each
ed with an opaque screen. Both compart-
:n filled with the same fluid, and a strip of
d in each; the connection was established by
lvanometer. Under ordinary circumstances,
urrent would be generated in the apparatus;
g the screen from either of the divisions so
light to fall on the platinum, the needle of
er was considerably deflected from its original

length to the important discovery, that a hydro-e in its passage through a single thermo-battery, generating either heat or cold at its junctions; the its direction is opposite to that of the thermo-el which is generated by raising the temperature of t the latter, when its direction is opposite to that produced by cooling the same points. The a adapted for testing the difference of temperatur hydro-electric current is *Peltier's Thermo-electric* consists of two strips of different metals, *ex. gr.* bismuth, laid one over the other in the form of a dered together at the point of intersection. Two metal ends of such a cross are connected with t single hydro-electric battery, and the other two v galvanometer. As the stream flows through the needle of the galvanometer is deflected, from w whether these points have been heated or cooled. current may be allowed to act alone for some minu pend it and connect both ends of the cross with the the same result is obtained. If the cross be mad and bismuth, the junctions are heated when the cu from the former metal to the latter; on the contra cooled it goes in the opposite direction. Corresp have been obtained with other thermo-electric com as a general rule, it seems that heat is elicited wh current passes from a bad to a good conductor; th duced when these circumstances are reversed. lowered the temperature of a junction in an anti muth battery by the voltaic current as to freeze wa

§ 533.

Light is mediately a cause by which the electric in a body is disturbed, if it produce local heat, esp parts where heterogeneous substances touch. This light is easily explained by attributing it to the the of the solar rays (§ 425.); but the inferences th be justified in drawing as to the warming of the by the sun are of special importance. Since th earth may be regarded as a battery of heteroge and since its thermo-electric currents have for the same path as that in which its heat advances, it l inferred that during the rotation of the earth fro the heating of its surface by the sun's rays goes on direction, viz. from east to west, and that to th currents owe their origin; for they hold on thei

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[illegible]

to the formation of clouds, by which they are alway
It is well known that they generally occur in the
the year, and that they are most frequent in the
because the thermal state of the atmosphere is then
the best condition for taking up a large quantity
vapour. Now if a stratum of air fully saturated w
vapour be cooled but slightly from any cause whate
cessary condition is thereby fulfilled for a change in
gate form of the vapour, which is converted into mi
which form into mists and clouds. This process will g
these circumstances much more rapidly and abundant
cooler air, saturated with aqueous vapour of less d
lowered its temperature the same number of degrees.
densation thus produced disturbs the electrical equi
fore subsisting in the vapour, and the + electricity acc
the conducting surface of the drops. In proportion
mation of mist goes on the clouds become thicker,
vapour come together near enough to touch, and a
electricity is driven to the surface, which has the sha
dary; the tension of the electricity which is thus ext
necessarily increase, just as it does in an insulated con
is charged (§ 482.). Such clouds are then to be regar
insulated conductors floating about in the air, which
act agreeably to the laws of polar attraction and induc
478. 483.) on any bodies that come within the range
fluence. The origin of clouds negatively charged i
for thus: it is supposed that the positively electri
which float about in the higher regions of the atm
their inductive influence on other clouds nearer to th
themselves, attract the — electricity from the latter,
electricity discharged into them makes its escape to
and other projecting objects on the earth's surface.

The clouds thus charged with electricity, like all
trical bodies, exert a tendency to saturate themselve
the antagonist electricity, and thus to re-establish a s
librium. This interchange takes place either betwee
electrified clouds, or between the latter and the earth's
the former case there is commonly a mutual attrac
clouds, which will account for their moving in opposi
towards each other, as also for the changes in form
undergo. If the equalization of their electricities h
denly, the intervening stratum of air is penetrated
ning, which is merely a strong electric spark; its pat
zigzag, probably in consequence of the resistance it
in passing through the air it has itself condensed; eve
sparks given off by an electrical machine are of a zi
Several flashes frequently follow each other in quick

is the case when, on account of their relatively low con- g power, the clouds do not completely discharge them- at once. This corresponds to the residuum of sensible city, which accumulates on the surface of a battery that has lischarged, and thus causes a second or third discharge.

e *thunder* is produced simultaneously with the lightning. It ud report caused by the sudden rupture and dispersion of r by the passage of the flash of lightning; and is perceived ppen, on a very small scale, on discharging a battery. If the ver be at no great distance from where the explosion takes , he will hear only a sudden report of short duration; but portion as the thunder becomes more distant it will be ac- anied with a peculiar *rolling sound*. It is most probable that olling or pealing of the thunder is occasioned partly by the ent compression and disruption of the air by the lightning course of its passage, sometimes miles in length, through amp strata of air, which act as conductors; partly also e different distances from which the sound comes to reach rs; and partly to the recoil of the waves of sound from the the sea, and even from the clouds. Kämtz conjectures t is modified also by the interference of the undulations. ese various causes the original report is so affected, that er heard in a plain country sounds differently from that in a hilly one, and this again from that heard at sea; in- at no two places probably is it exactly alike. From the which elapses between the flash and the report, the distance cloud whence they proceed may be calculated by the ob- according to the laws which are known to regulate the ty with which sound travels.

e electrical discharges from the clouds fall the more readily iects at the earth's surface in proportion as they favour the ive action of the clouds, and aid the passage of the light- y the good conducting structure of their materials, by be- ll connected with the ground, and especially by their height gure, which should be pointed at the extremity. Hence ing most frequently strikes high houses, towers, trees, masts s, and the like.

e effects produced by the lightning in its course through depends principally on their conducting power. They ble, on a grand scale, the effects of powerful sparks from an cal battery. When it strikes any object it proceeds from oint along the best conductor that offers itself, so that it ot always choose the nearest path by which to reach the d. On arriving there, it is neutralized by the opposite city of the earth, and all its influence ceases. If the con- s be stout bars of metal, or any similar objects, which offer trifling resistance to the passage of the lightning, the discharge will take place without leaving any perceptible trace of its influence. If this is not the case, as when the lightning strikes either bad conductors, or conductors of insufficient capacity, or those whose continuity is broken so that there are intervals over which it must leap, or through which it must penetrate, then its effects are extremely varied. It fuses or calcines the substances through which it passes, as when it traverses wires that are too fine. It sets on fire such bodies as are easily combustible. It vitrifies earthy substances, especially such as are at all sandy (*a*). It splits into shivers those solid bodies which are bad conductors; and is destructive to life, both of man and of the lower animals (*b*). Sometimes a flash is emitted from the earth without any electricity being discharged from a thunder-cloud. This phenomenon is thus explained: when a cloud floats just above terrestrial objects, and by induction accumulates in them a great quantity of the opposite electricity, and then suddenly discharges itself against a cloud higher in the air than itself, the sudden recoil of the latter occasions the phenomenon.

(*a*) When the lightning strikes a sandy soil it sometimes penetrates to a depth of 20 feet, fusing the gravel through which it passes, so as to give the appearance of a bore or tube; to these holes the name of *fulgurites* has been given, and their electrical origin, which was long held as doubtful, has been fully proved by Beudant and other French philosophers, who artificially produced similar effects by means of an electrical battery.

Almost all these cavities which have been traced to a greater depth than some 20 or 25 feet are found to terminate in a collection of water; so if we compare the lightning to an electric spark, the cloud to the conductor, the mass of water to the discharger, then the superincumbent bed of sand will answer to the interposed substance which is pierced by the passage of the spark.

(*b*) On the morning of June 2., 1839, a flash of lightning struck a battalion of French infantry on their march from Mezières to Weissenburg between Mouzon and Stenay: 200 men were struck by it to the ground, and on rising blood was seen to issue from their mouths, noses and ears: two men were killed on the spot.

The precautions to be taken in order to secure ourselves from a stroke of lightning will be readily seen from a consideration of the preceding paragraphs, and from a knowledge of the laws which regulate the action of the electricity obtained from the machine. The chief thing to be attended to is to avoid coming too near to any good conductors. If out of doors, do not take refuge under a tree or any other high object, do not move with such velocity as to accelerate the process of evaporation, walk in the middle of the street rather than near the houses: if within doors, place yourself in the middle of the room, away from the walls, bell-pulls, or any other conductors of electricity.

Water-spouts and *whirlwinds*, as also *hail*, which not unfrequently accompany storms, are among the aërial phenomena that have not yet been satisfactorily accounted for; atmospheric electricity may however be regarded as at least a co-operating cause by which they are generated.

Water-spouts observed at sea, and the pillars of sand seen generally in the great deserts, resemble huge funnels depending from the clouds. They have a remarkably quick and tortuous motion, and frequently emit flashes of lightning from their interior. When they arise at sea, the water immediately beneath them is put into a state of rotation; by which means it is drawn up to the water-spout. When this phenomenon occurs on land, dust, sand, and other bodies are raised in like manner. The force with which this motion is generated is prodigious. The masts of ships have been broken by it, the vessels themselves have sometimes been raised up by it and then sunk; whilst on land trees and even houses have sometimes been unable to withstand its violence.

There is a very difficult problem to be solved with regard to hail, which is evidently formed in the atmosphere, and which occasionally falls in pieces large as a man's fist, *viz.*, *how* so many thousand tons of ice can be formed and supported in the air?

§ 540.

After Nollet and Winkler had almost simultaneously (about the middle of the last century) discovered the electrical nature of lightning, Franklin (1753) applied himself to invent some method by which the lightning might be conducted to the ground, and its destructive effects guarded against. The *lightning conductors* which he invented were rods of metal, of sufficient thickness, terminating in a point, which projected some distance above the highest part of the building near which they were fastened; their continuity was unbroken throughout, and their lower extremity was driven some way in the ground: by this simple contrivance buildings, especially such as are filled with inflammable materials, are secured against the destructive action of lightning; the apparatus, with slight modification, has been applied also to ships. In the erection of a paratonnere the object to be secured is, that when it causes the discharge of an electric cloud, it alone should conduct the lightning to the ground without the building it is intended to protect or any of the neighbouring ones contributing in the slightest degree to re-establish the electrical equilibrium.

Since the original invention of this most useful apparatus various improvements have been introduced in its construction, and an attempt has been made to find some method of measuring its protective power. In the erection of conductors the following rules are generally attended to; if of iron the upright rods are generally about 2 inches thick and they rise at least from 5 to 6 feet above the highest parts of the building they are to defend, their ends are armed with a truncated point generally of copper gilt. It is assumed that a paratonnere of this kind is effective within a circle of 30 feet, that when several are erected they ought not to be more than 60 feet asunder. According to the experiments of Professor Charles it would seem, however, that a paratonnere does not protect any object whose distance exceeds twice its own height above the object. A metallic connexion is carried on from the projecting rod uninterruptedly to the ground: for this purpose a thinner bar, generally about ½ an inch thick, is used; but sometimes strips of other metals are employed, and occasionally even wire. Whatever kind of conductor may be selected, it is necessary that it should go over the roof and not merely down from the upright rod above the building; care should especially be taken that wherever the parts are joined there should be a pure metallic connexion; further, it is advisable that it should be carried at some little distance from the roof and walls of the building; that it should not pass through any combustible substance; that it should be kept away from any metal in the building itself, such as bell wires and the like; that if the roof be of metal the conductor should be carried clean over it and over any metal gutters and spouts. The ends of the conducting rods or wires ought to be carried to a place where the earth is itself a good conductor; if into a pool of water so much the better. If this cannot be done, select as damp a spot as can be found, and let the conductors terminate in three or four divisions a few feet under ground and not close to the building. Powder-magazines, laboratories, and similar edifices, containing substances that would readily ignite, require to be secured with especial care against lightning. To prevent the lightning communicating at all with the building, tall poles like masts rising higher than any part of the building are placed round about it at distances of from 6 to 10 feet; the tops of these masts are armed with paratonneres, and, according to Professor Charles's observations, the distance of one mast from another should not exceed one-fourth of its height. In the construction of edifices requiring extra care cure them from lightning all unnecessary projections ld be avoided and as small a quantity of metal as pos- should enter into their construction.

he phenomena of lightning, and the destructive effects h sometimes follow when it strikes a building are ex- lified by means of a well known piece of apparatus called *nder-house*, used with an electrical machine; by it the ty of lightning conductors is illustrated, and the iden- of the lightning and of ordinary electricity is fully lished.

§ 541.

mbent lightning, usually seen during the warm summer playing in the horizon, is another well-known elec nomenon. It consists in a succession of luminous flashes llowing each other and each of but transient duration. t like thunder is heard to follow and the light is often t the same time in the most opposite regions of the xtending over a very considerable space. It has been d beyond doubt that in many cases it is owing to the lightning which attend storms happening at that very places below the horizon; but in other instances, believes it to be an electrical phenomenon altogether in- t of any thunder-storm, owing to the efflux of strongly ted electricity which meets with no antagonist electricity ighbouring strata of clouds; similar therefore to what the experiment with the lightning table described in

§ 542.

r electrical phenomena, but less generally known and less y noticed are those tufts of light occasionally visible air is in a highly electrical state on pointed objects, such ps of the masts and the ends of the sail-yards of vessels, ps of lightning conductors, on the ends of bayonets, and s even on the ears of horses; the ancients gave to this name of Castor and Pollux: in modern times it has re- rious names, as St. Elm's fire, Helen's lights, &c. The een to flow from such bodies as we have just named for of time, the discharge being attended with a crackling produces no perceptible effects, and is in all probability the equalization between the electrical tension of the at- and earth, resembling the emission of electricity from odies towards the conductor of the machine.

§ 543.

The *Polar lights*, the *Aurora Borealis*, and *Australis*, are luminous appearances in the horizon, less transient in their duration than either the lightning or the phenomenon described in the preceding paragraph; indeed they are sometimes visible for hours. They are of most frequent occurrence in the higher latitudes, more rare in the temperate zones, and within the tropics they are scarcely ever seen. In the northern hemisphere the illuminated part surrounds the north pole, in the opposite hemisphere it surrounds the south pole; hence the respective names of *borealis* and *australis* applied to the aurora. When the figure is perfect, which however it rarely is, it consists of a luminous strip of a circular form, enclosing with the horizon a dark segment of a circle whose centre seems to lie in the magnetic meridian. This arch of light undergoes many changes in the beautiful colours which compose it, and emits many flashes of light. From time to time it throws up sparks of light of all colours, and in every direction; these frequently reach to the zenith and form a kind of crown. The greatest height to which this radiant light extends in the atmosphere is somewhere about fifteen miles. Sometimes the entire heavens appear illuminated above the arch to the very zenith; it is asserted that when the northern lights are unusually brilliant, very peculiar noises have also been heard.

From experiments and observations made on this subject, especially by Hansteen, it appears that the polar lights do frequently, but not always, affect the magnetic needle, deflecting it several degrees, just as the electric current deflects the galvanometric needle (§ 450. and § 512.), whereas if a needle of copper or any other metal be substituted for the magnetic needle, no such effect follows. There is a great similarity between this phenomenon and the appearance presented on exhausting a glass flask and then discharging a stream of electricity into the vacuum, as is done in the *electrical aurora borealis*, § 493. Hansteen's observation is worthy of notice, that, shortly before the aurora borealis is seen, the terrestrial magnetism displays an unusual intensity, which however diminishes on the appearance of the northern lights, and gradually sinks again to its ordinary standard.

From the resemblance of this phenomenon to others of an electrical nature, and from the fact that it frequently affects the magnetic needle, it is held almost universally to be of electric origin. Thienemann, who during his residence in Iceland had frequent opportunities of seeing this phenomenon, considers it to be caused by electrical discharges in the fine feathery clouds in [illegible]

se northern regions where thunder-storms are unknown; the
se, too, which has sometimes been observed to accompany the
hes of light, is by him referred to an electric origin.

§ 544.

t is generally believed that we are warranted in saying that
le the functions of life are performed, an uninterrupted de-
pment of electricity is maintained between the nerves and
scles of animals, at the surface of the skin, and especially in
rogeneous organs. The precise origin from which this
ply of electricity is derived is still unknown to us; some con-
r it to be an effect of the organic process of life in general;
rs that by means of the contact, or by some chemical dif-
nce in the nerves and muscles, the electricity existing in the
nal subject in a state of equilibrium, is made to acquire a
ree of electrical tension, and that this constitutes the source
i which it is supplied; others again consider electricity and
ous energy to be identical.

Soon after Galvani's important discovery, by which it was thought that the existence of a peculiar animal electricity had been ascertained, Alexander von Humboldt, Pfaff, and others, found that when the spinal nerve and the muscle of a frog's thigh were placed in immediate contact or were connected with an insulated piece of muscular flesh, contractions took place in the latter just as if it had been brought into contact with dissimilar metals. In like manner traces have been detected of an electric current in living bodies, by connecting two remote portions of a nerve, or of the muscle belonging to it, with a very delicate galvanometer.

Dr. Donné of Paris is one of those who seek for the source of this electrical excitement on the surfaces of the inner and outer skins, attributing alkaline properties to the former and acid properties to the latter. He made one end of a platinum wire to communicate with the outer, and the other with the inner skin of the mouth; within the circuit thus formed he introduced a delicate galvanometer, and found evident traces of an electric current which answered to this hypothesis. Matteuci, however, is strongly persuaded that a current produced thus after the death of an animal, soon ceases, and that consequently it could not have been owing solely to the chemical influence of the fluids transpired through the two skins. Wilson Philipp, on the contrary, showed how in certain cases the functions of the nerves might be discharged by a hydro-electric current, for

[illegible]

[illegible] assimilat

[illegible]

[illegible] These fishes be

[illegible] immediat

[illegible] other [illegible]

the needle, and partly by its magnetizing needles. Matteuci, and more recently Lineari, have succeeded in getting distinct sparks from these creatures.

lectricity seems to play an important part in the various es of the development of plants. Thus flashes of light have seen to be emitted from many plants in full flower soon sunset on sultry days. It has further been ascertained, by ns of galvanometric experiments, that electric currents are rated in the interior of their substance, although their inten- is but small; and that an uninterrupted development of elec- ty is maintained by the exhalation of carbonic acid in the osphere, especially during the germination of the seed, and, ed, throughout the entire process of vegetation.

The luminous phenomena in plants have been most diligently noticed by Zawadski, who observed them to happen principally in orange-coloured flowers (Calendula officinalis, Tropæolum, Lilium bulbiferum, Tagetes patula and erecta); that they occurred most frequently in the months of July and August, and that the same flower discharged a number of flashes in succession. — Dr. Donné has performed a number of experiments in the course of his investigations into this subject. He has found that in many fruits the current runs from the stem to the eye, while in others it flows in an opposite direction. Blake, who has established the existence of these currents by similar experiments, thinks he has discovered that they run from the stems to the surfaces of leaves; that he has verified their course to be as has been just said, by the chemical decompositions they effect; that, lastly, the leaf itself is rendered positive, and the ambient air negative. — Pouillet has rendered essential service to this branch of science by discovering that positive electricity is given out from plants when germinating. This he ascertained by connecting some that were in this stage of vegetation with a condensing electroscope. From his experiments he inferred that a surface of 1000 square feet would give out sufficient electricity to charge the most powerful battery.

§ 547.

It is evident from all that has been advanced in the preceding section as to the influence of the electric current upon magnetic needles, that the former acts upon the latter like a force which exerts itself laterally, and, indeed, at right angles to the line of its direction. If this were the only force in operation on the needle, its axis would necessarily take a position perpendicular to the course of the current. But the magnetic influence of the earth acts upon it at the same time, and imparts to the needle its polar position. From the conflict of these two forces an effect is produced which may be estimated in the same manner as any other compound motion (§ 23.), and by which the different degrees in which the needle is deflected may be accounted for.

The only case in which the position of the needle undergoes no change is when the magnetic current and the "vis directrix" of the earth act in the same direction. The magnetic intensity is then equal to the sum of the two forces. When these forces act in opposite directions the resultant is equal to their difference. The needle is either less powerfully retained in its normal position, or it is completely turned round, when the magnetic intensity exceeds the earth's directing force: in this position of the needle the degree of intensity is measured in like manner (see 4. in the preceding §). When the forces act at any angle whatever, then, by the law of the parallelogram of forces, the needle will acquire the position of their resultant. This is, of course, the case when the current runs parallel to the axis of the magnet (see 1. and 2. in the preceding §).

Hence it is seen why the amount of the needle's deflexion by the passage of an electric current, either above or below it, in a direction parallel to its axis, is invariably dependent on the ratio subsisting between the above-named forces. As a general rule, the greater the intensity of the current, and the less the "vis directrix" of terrestrial magnetism, the greater the deflexion of the needle. If now one of these forces be constant, and we shall be sufficiently near the truth in assuming the earth's magnetic influence to be so at all parts of its surface, then the other force, i.e. the intensity of the electric current, may be measured by the angle which the needle is deflected from its normal position. Hence the propriety of using a magnetic needle, both as an index to show the existence of an electric current, and as a measure of its intensity. It is almost needless to remind the reader of its application in the construction of galvanometers (§ 512 and 522).

B. — *Influence of Electric Currents on each other.*

§ 548.

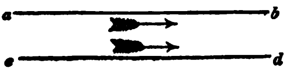
No discovery in natural science excited more general and
ly interest than Oersted's. The most distinguished philoso-
rs throughout the world recognised its importance, and en-
voured by repeating and varying his experiments to trace still
:her this extraordinary property of electricity. They hoped by
ans of Oersted's fundamental experiments they should be enabled
unravel the mystery in which the connection between electricity
. magnetism had hitherto been shrouded. New facts were
ght for experimentally which might serve as indisputable evi-
ce of the identity of electricity and magnetism, or from which
night be proved that both were merely modifications of the
e fundamental force. Although the object thus earnestly de-
d has not yet been attained, the active spirit of inquiry that
been called forth has led to important and approximating
clusions. Ampère, who considered Oersted's experiments
n a point of view common to them all, selected *the mutual re-*
on of electric currents to each other for the special subject of his
estigations. He was led to the important discovery that, *the*
tricities in a state of motion, i. e., *as electric currents, act attrac-*
ly and repulsively on each other according to a certain law, in a
nner resembling the polar attraction (§ 474.) of statical elec-
ity, *i.e.*, of electricity in a state of tension.

By means of his discoveries a connection, which might indeed
e been inferred from Oersted's experiments, was clearly shown
subsist between electricity and magnetism. Additional im-
tance attaches to these discoveries, as Ampère deduced from
m a highly ingenious theory, in which the phenomena of mag-
ism were referred to electric currents, or in which, at least,
mutual influence of electricity and magnetism admitted of an
y solution, and in which the various electro-dynamic pheno-
na were collected into a whole.

§ 549.

Ampère found that the influence of electric currents on each
er varied with their position and direction. The following is
fundamental law according to which these different influences
: —

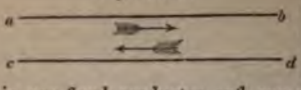
Fig. 205 a.



Parallel currents attract each other when they flow in the same direction, as in *fig.* 205 *a.* where *a b*, *c d* are the currents, whose

directions are indicated by the arro
their directions are opposite, as in *fig.* 2

Fig. 205 *b.*



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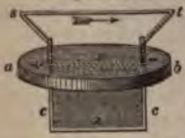
on
tra
of

viz, one fixed conductor, and one wh
great ease. The constructions adopte
are various; the following are perhaps

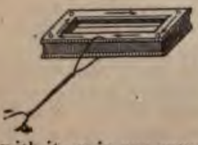
1.) *De la Rive's Floating Current*, f
simplest of all
It consists of a
which is fixed
battery, compos
copper *c c* (or be
with an amalgan
pole of the copp
of the zinc at —
tinum soldered

Fig. 206.



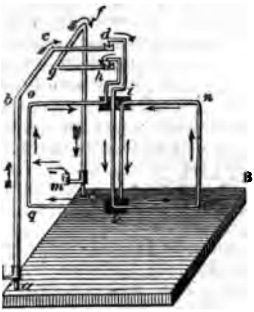
swer best. They should be made to
and a fine piece of silver or copper
connected with them in some simple m
float is to be placed in a vessel contain
and suphuric acid as the exciting fluid
will be generated in the direction fr
the arrow in the *fig.* The second part o
the second electric current, to which t
sition is to be given, with respect to th
copper wire, coated over with silk, is
ten or more times, in the manner of
together round a wooden frame abou
three inches wide, as shown in *fig.* 20
the wires, fro
are carried to
a simple Dani
sen's battery
purpose. T
put in such a
rent flowing
may be parall
the float, or
with it, or in one opposite to it, when
mena will follow in each case.

Fig. 207.



) *Ampère's Electro-dynamic Apparatus.* — *Fig.* 208. two stout copper wires *abcd*, *efgh*, stand on the board AB; as the figure shows, they are bent twice at right angles, and terminate at *d* and *h* in two mercury cups; their middle parts will therefore be at right angles to each other. These two bent wires serve partly as fixed conductors of the electric current, but principally as supports of the circulating current. The moveable conductor is bent in the form of a

Fig. 208.



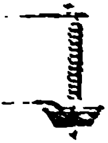
ıle square *ikln* and *ikqo;* it is insulated at *i* and *k* by tion in a piece of cork; the ends at *d* and *h* are fur-ed with steel points; the battery is set in action by ng these points in the mercury cups *d* and *h*. This uctor is completely supported by the upper cup *d*, and s with perfect freedom upon its steel point. To render motion as free as possible from friction, it is well that oottom of the cup *d*, on which the point rests, should be ass or agate, while the other point is but just immersed in nercury in the cup *h*. To connect the whole of this ratus with the hydro-electric battery, two little arms on the wire at *a* and *e*, carrying binding-screws at their mities. The apparatus may either be immediately con-ed with the poles of the battery at *p* and *m*, or a gyro- may be used to effect this object.

ow if the current run in the direction indicated in the e by the arrows, the part *oq* of the moveable conductor be attracted by the part *ab* of the fixed conductor in h the current has a direction parallel to that of the er, but it will be repelled by the part *fe* where the cur-runs in an opposite direction.

perform another experiment which also depends on bove law of the attraction of currents flowing parallel to other and in the same direction, we may make use of,

) *Roget's oscillating electrical spiral.* — *Fig.* 209. A l + —, not coiled very closely, of thin copper wire, that it may easily be compressed or elongated, is hung ally with its upper end through the conductor which

Fig. 209.



projects from one pole of the battery, wi the point of its lower extremity just touc the surface *q* of some quicksilver whi connected with the other pole of the sa battery. On establishing the connectio spiral vibrates longitudinally, becaus every contraction of the coils compo helix, the connection is broken, the we of the wire then causes its lower end s to sink into the mercury and the action of the battery restored.

§ 550.

If electrical currents do not run parallel to each other, t display a tendency to move towards the same line and to same direction on that line. This is shown in the follo cases —

Let two rectilinear currents *a b*, *c d*, *fig* 210 *a*. and *b*. form angle whatever, then they must either attract or repel each oth The former will ensue if both currents flow towards, or from th angular point as represented by the arrows in *fig*. 210 *a*.; but one current run towards the angle, and the other from it, as in *fi* 210 *b*. then they will repel. both these cases the tendency abo spoken of is seen in operation.

Fig. 210 *a*.

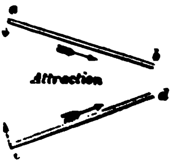


Fig. 210 *b*.

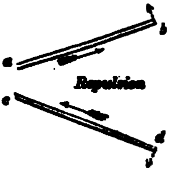
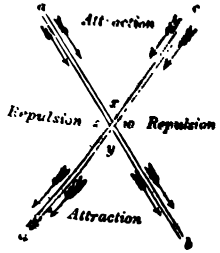


Fig. 211.



If two rectilinear currents *a b*, *c d* *fig*. 211. cross each other, then b the preceding case they will attr each other between the verti angles *x* and *y*, and repel between and *w*. The result will be that bo conductors will endeavour to take u a position in which the currents th flow through them may have similar direction.

Expt. To verify the correctness of this assertion, use th floating current described in the preceding section and represented in *fig.* 206. and bring to it the fixed current *fig.* 207. to which such a direction is to be given that it may answer to the several cases given above.

If, however, the reader prefers using Ampère's apparatus, hang in its cup the conductor *i k l n o*, *fig.* 212. and bring the stable conductor so near to the under side of the rectangle *k l* that the direction of its current may make an angle with *k l*. The conductor represented in *fig.* 207. will do, or that one of stout copper wire represented by *q r s t u* in *figs.* 212. and 212 *a.* through which the stream takes its course in the direction pointed out by the arrows, this conductor being used as shown in both the figures to connect the battery and set it in action.

Fig. 212.

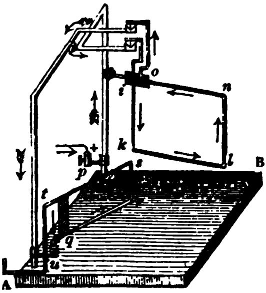
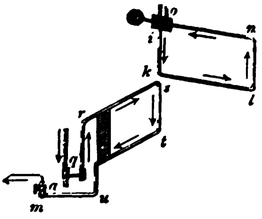
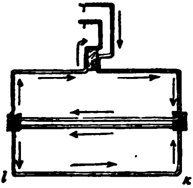


Fig. 212 *a.*



In *fig.* 212. *k l* and *s t* will be attracted: in *fig.* 212 *a.* they will be repelled.

Fig. 213.



To test, by means of this apparatus, the influence which cross currents exert on each other, it will be necessary to suspend the moveable conductor, *fig.* 213. in the mercury cup and to place under the lower part of its current *k l* either the conductor *fig.* 207. or one of the conductors *t s* or *r s* *fig.* 212. in such a manner that the directions of the two currents may cross each other.

Fig. 214 a.

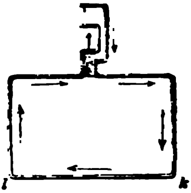
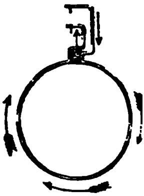


Fig. 214 b.



In like manner if the circular conductor *fig.* 21 pended in the cup it will acquire such a positior current flowing in the lower part of the ring may direction equal and parallel to that of the curre under it.

In performing the last experiment a simple pi paratus may be used of which a sectional view is *fig.* 215 *a.* and a horizontal one in *fig.* 215 *b.*

Fig. 215 *a.*

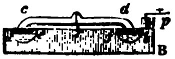
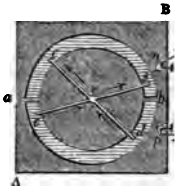


Fig. 215

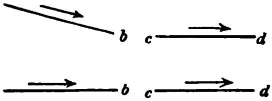


In the wooden disc AB is a circular trough two opposite points by the insulating partitions *a* consequently divided into two semicircles. In tl of the trough there stands an upright steel point, c copper needle *c d* runs, with an agate cup; the e needle which are of steel, are bent downwards so the mercury with which the trough is filled. I needle is a second *e f*, whose ends are also turne reach the mercury, and which can be moved rou hand. The current runs from the binding-screw trough, thence through the two needles into the returns from *m* to the battery. When the needles position given in *fig.* 215 *a.* repulsion obtains; v position is that represented in *fig.* 215 *b.* attraction soon as the angle *e r d* is diminished by turning round the wire *e f* which conducts the current.

§ 551.

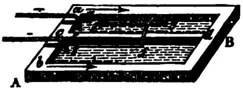
Two currents following each other in the same direction, as o the different parts of the same current, repel each other. That this effect must necessarily arise follows from the phenomena explained in the preceding section; for so soon as the angle between the currents *a b* and *c d* *fig.* 216. becomes very obtuse, *b* and *c* repel just as if *a b* and *c d* were in the me straight line.

Fig. 216.



Expt. Ampère has endeavoured to verify this particular case experimentally by means of the apparatus represented in *fig.* 217. It consists of a long rectangular box AB, divided by a non-conducting partition *c d* lengthwise into two parallel cells. To render the insulation perfect it is advisable to wash these compartments over with a thick solution of shell-lac. Connect one of them *a* with the positive, and the other *b* with the negative pole of a common battery; place a copper wire covered over with silk *e f g h* on the mercury as a circulating conductor, this wire must be so bent that it may reach from one cell over into the other: its two horizontal arms will therefore run one in each of the cells parallel to the partition, the ends of these arms are slightly bent downwards, and thus the battery is set in action. At the moment when the circuit is completed, the floating conductor may be seen to move forward on the surface of the quicksilver from the poles *a* and *b*.

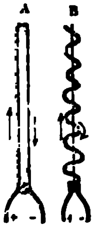
Fig. 217.



§ 552.

If two fixed currents of equal intensities flow close together nd parallel to each other but in opposite directions, as in *fig.* 18 A. then their combined influence on a current moving freely s *nil*, that is, they exactly neutralize each other. The same happens when one current circulates round the other in the manner epresented in *fig.* 218. B.

Fig. 218.

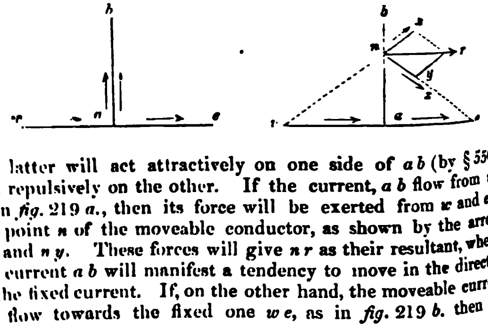


Expt. The truth of the preceding remarks may be tested by sending a current along copper wire, bent in the form shown in *fig.* 218. A and B, taking care in bending the wire that no two parts of it shall touch; then send a current through a moveable conductor, and place the two so that one or other of the above-named actions may be exerted on the free current. It will be seen that the action of the latter continues unaltered.

§ 553.

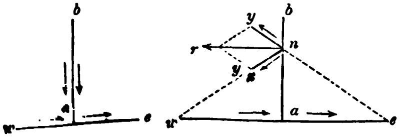
If a moveable electric current, *a*, *b* (*fig.* 219 *a.* and *b.*), flow in a direction at right angles to another which is fixed *w e*, then

Fig. 219 *a.*



the latter will act attractively on one side of *a b* (by § 550.), and repulsively on the other. If the current, *a b* flow from *w e*, as in *fig.* 219 *a.*, then its force will be exerted from *w* and *e* on the point *n* of the moveable conductor, as shown by the arrows *n r* and *n y*. These forces will give *n r* as their resultant, whence the current *a b* will manifest a tendency to move in the direction of the fixed current. If, on the other hand, the moveable current *a b* flow towards the fixed one *w e*, as in *fig.* 219 *b.* then the

Fig. 219 *b.*



ultant *n r* will have an opposite direction, and the free current will show a tendency to move in a direction opposite to that *able current.*

this law of attraction and repulsion the rotatory motion of urrents about each other depends. For instance, if the t *w e* (*fig.* 220 *a.*) be a horizontal circular current, then

Fig. 220 *a.*

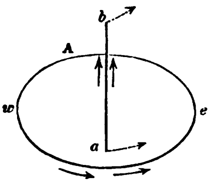
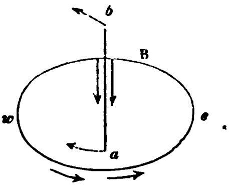
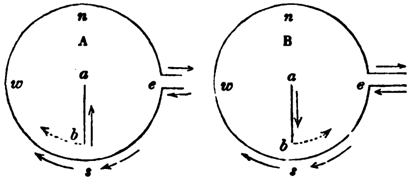


Fig. 220 *b.*



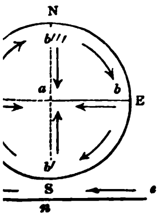
e current *a b*, which flows out from it, will revolve in the direction with *w e;* but if *b a* flow towards *w e*, as in 0 *b.* then the direction of its current will be opposite to f *w e.* Again, if *a b* (*fig.* 221.), be a rectilinear current,

Fig. 221.



e o. revolving about the centre of the circular current, , then its rotation will be in the direction of the circular ıt, when the current *a b* runs from the circumference towards ntre, as it does in *fig.* 221. A ; but if it be transmitted from ntre towards the circumference, as *a b* (*fig.* 221. B), then it volve in a direction opposite to that of the circular current.

Fig. 222.

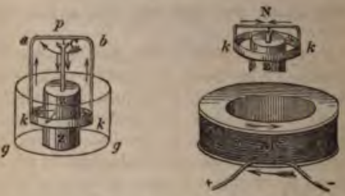


In like manner, but in a lower degree, there will be a rotation of the current, *a b* (*fig.* 222.), if a rectilinear current E. W., be transmitted near to it. *a b* will in this case run, as is indicated by the arrows, in a direction parallel and similar to E. W., the currents will therefore attract each other, and *b* will be carried to *b'*, on arriving at this point, *a b'* is repelled by E. N. and is attracted by N. W.; the free conductor *a b'* will consequently move on to *b''*; when it has reach this point, repulsion ensues between the parallel and contrary currents $b''a$ and E. W.; on arriving at b''' it is again attracted by E. N., and thus the current ab is maintained in a constant state of rotation. If the stable unlimited current E. W. run from E. to W., and the free current be to the N. of the other, then, as the curved arrow in *fig.* 222. shows, it will turn about a in the direction from the E. through the S. to the W. and so on, like the hands of a watch.

There is a great variety in the apparatus which has been constructed to give this rotatory movement to a moveable conductor by means of an unlimited rectilinear or circular current: we shall now proceed to describe only a few of the best and simplest specimens.

First Expt. Rotation of a vertical current about a horizontal circular current.—*Fig.* 223. represents Pineau's simple apparatus. It consists of an amalgamated zinc cylinder Z Z, on which is soldered a stem Z C of copper wire, carrying on its summit a small mercury cup C. The base of the cup should be of agate to diminish friction; on it rests a thin copper wire $k\,a\,b\,k$, supported by a steel point p, this frame carries a copper zone. The zinc cylinder with this rotating conductor is placed in a glass of water and sulphuric acid. The whole, thus arranged, constitutes a simple hydro-electric battery, in which the current is transmitted from the zinc cylinder through the liquid conductor to the ring of copper, thence to the two arms of the bent copper frame, as shown by the arrows, and passing through the steel point p, it returns again into the zinc cylinder.

Fig. 223.



Now lay on the upper edge of the glass the coil M, which is made to fit it exactly; join its ends (+ −) with the poles of a constant battery, and the current which ascends vertically will revolve in the same direction as the current that passes through the coils of wire.

Substitute a copper cylinder for the zinc one Z, and an amalgamated zinc ring for the copper one; the current will

e arms *a k*, *b k*, and the direction in which the
'olves will be reversed.

pt. Rotation of a moveable horizontal current about
ı circular current. — The apparatus described in
ʒ experiment will do to perform this also; the
ɔn required will be to give the zinc or copper
a very short conducting-wire, so that the current
horizontally either from or to the coil of wire;
n by the arrows in *fig.* 223. N; the direction in
otation will happen depends on whether the
from or to the coil.

hed to excite in the moveable conductor a more
l lasting current than the simple battery we
ꞩcribed is capable of generating, then combine
:s on the principle of a Daniell's or a Grove's
ery, by separating the electro-motive metals by
ɔrous earthenware cell, which should be inserted
'essel, and then add the appropriate liquids to
metals.

ɔt. Rotation of the fluid conductor about a cir-
— The fluid conductor may be made to take
he solid, *i. e.*, if we have no metallic conductor
described in the preceding experiments, then
ıelf will begin to revolve. The same apparatus
is case also, only substituting for the moveable
'*fig.* 223.) an open cylinder of the same metal,
to the glass vessel. Fill it with any suitable
ure of liquid sal ammonia and muriatic acid is
r recommends; and to increase still more the
the current, a solution of sal ammonia may be
:y on the copper cylinder) and the current will
e zinc cylinder to the copper ring, *i. e.*, it will
the centre to the circumference. Now surround
h the coil of wire M, whose ends are to be con-
he poles of a simple battery; on connecting the
fluid will revolve agreeably to the laws with
e already acquainted. Its rotation will be still
tly shown by placing small floating bodies on
f the liquid.

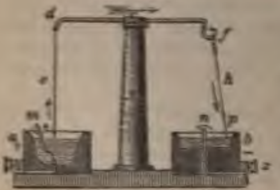
:pt. Rotation of a horizontal current by the action
of unlimited length. — This phenomenon is ob-
bringing any rectilinear conductor, *e. g.*, one
ʒalvanometer frame (*fig.* 207.) to the horizontal
e second experiment.

t. Rotation of a circular current by the action of
ırizontal current. — This is Savart's interesting
the second experiment, in which the circular
ıe multiplying coil is entirely dispensed with.

206. and if the position and course of the current
as is represented in the diagram, it will be attract
the same manner as the rectilinear conductor, whe
N. pole of the magnet is presented to it, and it will be re
when the S. pole is brought near.

Second Expt. Faraday's Rotatory Apparatus for a
current about the pole of a fixed magnet, and for the po
magnet about a fixed vertical current. — *Fig.* 232. gi

Fig. 232.



vertical section o
apparatus. A suffic
stout copper wire
fastened on the u
column of wood *g*.
the end *f*, which
nates in a hook,
hangs a fine pl
wire, whose low
reaches the troug
mercury; this wir
pended by a no
that it has perfectly free motion; the platinum wi
the contrary, is soldered to *d*, and descends vertically
wooden cup *a* of mercury. In the centre of the ve
the vertical bar-magnet *n*, a magnetized sewing-nee
answer the purpose, fastened into a copper tube, whi
through the bottom of the vessel. A small glass be
fixed to the end of the wire *h*, that it may not come
tact with the magnet. At the bottom of the cup
magnetized sewing-needle *m*, attached by a fine th
platinum, but still with room to play; by means of
spiral of platinum wire, which can be pushed on to
needle may be made to swim vertically in the m
The apparatus is connected with the poles of a c
battery by the binding-screws *c* and *z*, from which
wires run so as to connect them with the two cups
When the battery is thus set in action, the current ci
through the conductors as represented in the *fig.*
arrows, and the north poles of both the magnets are
upwards; the moveable conductor *h* therefore revolv
the pole *n* of that magnet in the same direction as th
of a watch, whilst the pole of the magnet *m* turns i
trary direction around the fixed conductor *e*. — Rev
direction of the current, or place the S. poles of the
uppermost instead of their N. poles, and the rotati
be inverted also.

Third Expt. Rotation of a magnet about its own
Fig. 233. represents a simple apparatus by which to

this experiment. It consists of a glass tube *a b* about three inches long and one inch wide. Its lower end is closed with a cork, through which an iron wire passes, projecting slightly beyond the cork, and terminating in the point *e*. The lower end of this wire is soldered into a copper plate which is connected with the binding-screw *z*. In the upper end of the tube is inserted a copper ring *b d*, which is connected from *d* externally with the other binding-screw. The glass tube is then filled with mercury up to the ring, and the little bar-magnet *s n*, rounded off at both ends, is immersed in it till it touches the iron pin *e*. One half of the magnet will therefore rise above the level of the mercury, in which, as it touches the iron at a single point, it will have a perfectly free motion around its own axis. Next connect the binding-screws with the poles of a powerful constant battery, and the magnet will begin to turn about its axis. — If the current proceed, as it is represented in the figure, from the copper ring *d b* to the magnet, its rotation will follow in the direction of the electric currents which surround it. Reverse the direction of the current, so that it may proceed from the magnet to the copper ring, and the magnet will turn in the contrary direction to the currents which encircle it. From Ampère's law about the action of electric currents on each other (§ 533.), we should have inferred that these must be the directions taken. See also *figs.* 233 *a.* and *b.*

Fig. 233.

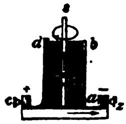


Fig. 233 *a.*

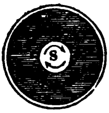
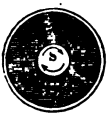
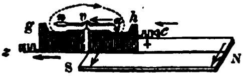


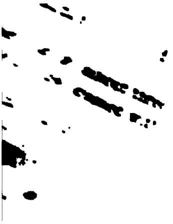
Fig. 233 *b.*



Fourth Expt. Schweigger's rotatory apparatus, in which horizontal currents sent through the pole of a magnet impart to it a circular motion. — In *fig.* 234. *g h* is a section of a wooden plane in which a circular trough *t t* is cut to contain quicksilver. Through the centre of the plate the copper wire *w* passes, the extremity of which is furnished with a steel point. On this point a copper needle *n a*

Fig. 234.





sels. Place t
malgamate
given or.
23. N. o
light copper
p n, which is
copper bucket.
pour a mixture
ic acid to 4 or 6
the current will
mple battery from
inder to the zinc
il run from its point
s, in the horizontal
copper handle which
conductor, eccentrically
; thence it descends in
of the conductor parallel
om the zinc ring through
, whilst the currents which
magnet, flow horizontally.
ves, therefore, about the N.
; that about the S. pole from
therefore, turn in directions
the currents of the magnet.

el use a similar one of zinc and
substitute one of copper, one of
r still, and the current will ascend
or, or handle of the bucket, which
of the magnet and the rotation will
direction as that in which the cur-
agnet.

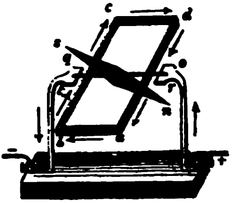
els be large enough when laid on the
ove freely round it, and if they also
poles upon steel points, they will
e magnet be a sufficiently powerful
th which we are already well ac-
ill be contrary to that of the rings.

rotating wheel between the poles
– A light wheel of thin copper
notched like a star, runs on
an axis terminating in points
which rests in the sockets of
a fork *ab* of copper wire, the
wheel may be about 3 or 3½
inches in diameter. Under the
wheel is a groove *q* in the

appears that the part of the current which inclines tow
terrestrial equator flows from E. to W. whilst that w
turned towards the pole runs from W. to E., or in othe
that the current as a whole takes such a position as the
supposed to exist in a dipping-needle has about its axis.

Expt. Such an electrical dipping-needle or
torium, may be constructed thus, according to E
fig. 240. Procure a light
frame, *a b c d* which is
with two common sewing
o and *q*, that serve as
about which it can tur
Wind copper wire cove
silk several times ab
frame in the direction *a b*
let one end have a meta
nection with the trunnio
the other with that at *q*
trunnions are now to be

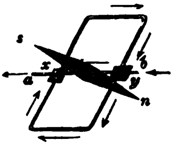
Fig. 240.



the bent parts of the metal stems *p r* and *m t*, w
widened out into little stages *r* and *t*, and ar
polished; the centre of gravity of the apparatus is
arranged that the frame may take a horizontal positi
place the whole so that the axis of rotation may st
pendicularly to the magnetic meridian, and con
binding-screws *p* and *m*, with the poles of a powe
stant battery, as soon as the current begins to flow
the wire, the frame will take the position represent
fig. To mark the position of the dipping-needle
board needle *s n* may be fixed in the middle of the
as to intersect the plane of the former at right angl

A similar result will be
with a common wire condu
241. insulated at *x*, and pla
the ends of its axis *a* and *b*
stages of *fig.* 240. if a su
powerful current be sent thro

Fig. 241.



On account of their frict
sometimes difficult to insure t
moveable conductors shall ta
proper position. If the experiment described above
fully answer, the failure is to be ascribed to the
friction, the same remark holds good with regard t
of the preceding experiments.

§ 563.

Every solenoid possessing tolerably free motion and through which a powerful electrical current is sent, will (in consequence of the influence the earth's magnetism exerts upon it) take such a position that the circular currents which run downwards will flow from E. to W., and those on the E. side will run upwards, its north pole will consequently point towards the N. (see § 554.), and its south pole towards the S.

> *Expt.* To show experimentally that a solenoid has a tendency to acquire the polar position just spoken of, and to rest in it, hang one, *fig.* 226., in an Ampère's frame in such a manner that its poles may stand E. and W. When in this position send through it a pretty strong current, it will begin to turn, and, after a few fluctuations, it will settle down in the polar position.
>
> The same result is obtained if the floating solenoid be used, *fig.* 227., only the electric current must be strong enough to overcome the resistance of the fluid to the motion of the apparatus.

In like manner a solenoid capable of revolving about a horizontal axis passing through its centre of gravity and at right angles to the plane of the magnetic meridian, will necessarily take a position coinciding with that of the dipping-needle, because the whole of the currents circulating in it are at right angles to this direction; they therefore as a whole, coincide with the position which each single current takes. The greatest practical difficulty consists in so constructing a solenoid, that it may have the perfectly free and easy motion that is indispensable to the success of the experiment.

§ 564.

The assumption that electrical currents circulate about the earth is consistent with the directing force they appear to exert on magnetized needles. For since by Ampère's hypothesis a variation needle may be regarded as a solenoid (§ 557.), it will take the same polar position as the latter, when the electrical currents supposed to exist in it acquire a position exactly opposite to that of the currents which flow in the magnetic equator of the earth, *i. e.*, they will flow exactly opposite to each other. This can however be the case only when the north pole of the magnet is that the electro-magnet retained for a length of time a able suspensive power (about half its full power); but t keeper were detached, the magnet entirely lost this pow nus further discovered, that electro-magnets acquire th ordinary suspensive power only when their keepers are with them; it is the magnetism excited by inductio keepers that imparts this power, for when the poles are connected they are scarcely able singly to support th of the keeper.

Several philosophers have attempted both experimen theoretically to ascertain the laws on which this suspensi principally depends, and by which it may be determine vestigations of this kind were first undertaken by Fech Negro, and Ritchie; they have subsequently been ca more fully by Jacobi and Lenz, and most recently by Pl main results at which they have arrived are the followin

1.) The amount of the suspensive force is immediately ent *on the intensity of the electric current* which circulat the iron; and it has hereby been ascertained, that the of the magnetism excited in the soft iron *is exactly pro to that of the electric current.*

By Ohm's fundamental law the intensity of the may be estimated from the magnitude of the electr force, and the degree of resistance to conduction th be overcome (§ 511.) in a short stout wire of go ducting power, such as copper. It depends, therefo cipally on the quantity of electricity passing thro helix; consequently, on the area of the electromot on the absolute force with which it is excited; if t be long and fine, on the density of the current, an number of members in the battery.

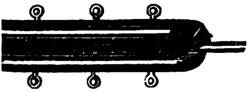
2.) If the intensity of the current continue the same, t net's suspensive force increases with the number of tur by the wire; or, *the total effect of all the coils is equal to of their effects if taken singly.*

3.) The attractive force of an electro-magnet increase mass of the iron composing it; and this increase *is pro to the diameters of the iron cylinders, their lengths being eq*

4.) The *structure of the iron* itself greatly modifies its in and, in fact, *the purer, softer, and more homogeneous the stronger the magnetism it is capable of receiving.*

5.) Lastly, it has been ascertained that, *the form of of iron, or of the electro-magnet, influences its suspensiv* Cylinders were found to carry greater weights than rec bars; and a hollow cylinder, from which a portion had away, so that it formed (*fig.* 245.) a long horse-shoe

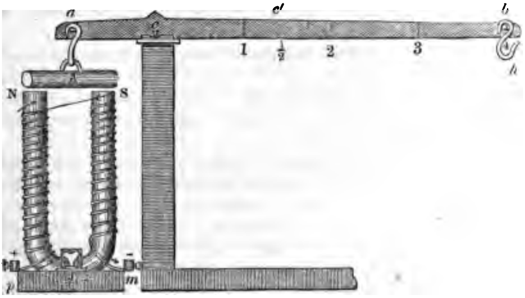
Fig. 245.



when viewed in the direction of its axis, but a very short one if taken as to its height, was capable of receiving a very great suspensive force; and lastly, a slight curvature of the polar surfaces added considerably to its power.

The following contrivance will be found convenient for estimating in a simple manner the suspensive force of an electro-magnet, either by weight or by human power of traction.

Fig. 246.



The horse-shoe N J S (*fig.* 246.), which stands vertically in a wooden foot, is fastened so that its arms point upwards. The manner in which the copper wire is coiled about it is seen from the figure. The ends carry two binding-screws *p* and *m*, which are either connected immediately with the poles of a battery of two elements, a carbon or platinum battery, or else it is connected with the latter by means of a commutator (*fig.* 203. § 546.). The different coils of the wire are insulated one from another by winding them so that they do not touch at any point; they are insulated with regard to the iron of the electro-magnet either by surrounding the latter with a silk band, or by coating it over with gum-lac varnish. The feeder A, which consists of a cylindrical piece of soft iron, is so fastened to the unequal armed lever *acb* that it moves at a short distance above the poles, whose faces are slightly hollowed out. The feeder having a free motion in this position, can be brought down so that its cylindrical surface just fits into the cavity of the poles beneath it. A stout hook *h* is attached to the other arm *b*; to it the scale pan is fastened, in which weights are laid to measure the magnet's power of suspension; or this force may be estimated by pressing or pulling the lever with the hand until the keeper is detached, in which case the true measure of the force is obtained by supporting the lever in the middle *c'*. It is scarcely necessary to add that in such experiments as we have been describing, the foot of the apparatus must be secured by a clamp, so as to render it immoveable.

This curious and powerful kind of magnet was discovered by Sturgeon in 1825. Subsequently Henry and Ten Eyk, in America, constructed some on a large scale. One horse-shoe magnet made by them, and weighing 60lbs., would support more than 2000 lbs. More recently electro-magnets have been made of the ordinary form by Joule and Radfort. *Fig.* 245. represents one of Joule's, which weighed 15 or 16 lbs., and carried a weight of more than 2500 lbs.

§ 569.

If a rectilinear electro-magnet be made to turn in a horizontal plane about its centre, it will act in the same manner as a declination needle, or a solenoid; that is to say, it will assume a polar position. If on its attaining this situation the current in its wire be reversed, the poles of the magnet will instantly be reversed, and the consequence will be that it will begin to revolve in order once more to regain its polar position, on attaining which its magnetism becomes again changed, and hence a perpetual rotation of the magnet about its middle. This rotatory movement, which in the case supposed was owing entirely to the influence of the earth's magnetism, may be rendered more violent by causing the unvarying poles of a common magnet, or of an electro-magnet, to act upon those points of the revolving one where the change in the current takes place. According to the laws of magnetic polarity there arises first an attraction between dissimilar poles; as soon as these, by the change in the current, become similar there ensues a powerful repulsion. This alternate action is maintained so long as the continuance of the electric current keeps up the temporary magnetism. Ritchie, who in 1833 invented these rotating magnets, first entertained the idea of applying this rotation as a motive power to machinery.

Fig. 247. and *fig.* 247 *a.* give a vertical and a bird's-eye view respectively of an apparatus of this kind, which, besides generating a rotatory movement, may be used as a contact-breaker. S N is a common horse-shoe magnet, with its poles permost: *nsc* is the small electro-magnet, which turns out the vertical axis *cd*, whose point rests in a depression the screw *m*: the poles *n* and *s* of the lesser magnet are a small distance from those of the great horse-shoe, whose les S and N pass through a wooden circular plate; between ese poles the two halves of a copper ring are let in, so as be insulated at *f* and *g* by two partitions of wood or ivory, hich part them asunder. From these points conductors e carried through the wooden disc, ending at its cir-mference in binding screws at *p* and *m*, by which the half ngs of copper are connected with the poles of a constant ttery. These two copper plates, acting now as the poles the battery, are put in contact with the ends *a* and *b* of e helix of wire, and thus the current circulates about the ectro-magnet. To insure a complete metallic contact be-een the points where the current passes off to the wires, d at the same time to reduce the friction to the utmost, it best to attach to the ends *a* and *b* some extremely fine atinum wire, twisted so as to form a fork (*fig.* 247 *b.*), d trace over the copper plate, which may be either amal-mated, silvered, or gilt. At the instant when these fine ires cross the bridges *f* and *g*, and touch the other copper ate, the poles of the electro-magnet are reversed, as is derstood readily from the remarks already made. The rtition *x* which projects above the copper plate, and which, ce those at *f* and *g*, may be of either wood or ivory, would sure that the current should be interrupted every half volution.

Fig. 247.

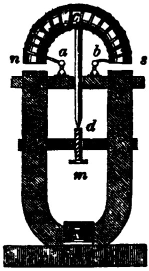


Fig. 247 *a.*

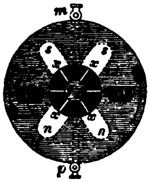
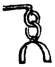


Fig. 247 *b.*



§ 570.

Many philosophers and mechanicians, in both the old and new world, were induced, from a consideration of Ritchie's rotating electro-magnet, to investigate, both practically and theoretically, how far electro-magnetism would be available, if applied as a motive power to machinery.

The principle on which all machines act that are *set in motion by electro-magnetism*, is mainly the great attractive force exerted by the dissimilar poles of an electro-magnet, and the subsequent change of this attraction into an equally strong repulsion, when, by the change of the current in the spiral, similar poles are made to act on each other. — We are indebted to Professor Jacobi, of Petersburg, for the most complete and varied investigations, both of a practical and theoretical nature.

A machine was constructed, according to the laws developed by Jacobi and Lenz, in 1831, its useful effect amounted to between ¾ and 1 horse power (§ 421.).

In consequence of what has already been effected, these machines possess a great practical interest, and since experience has ever shown that discoveries of this nature are not brought for years to the highest degree of perfection of which they are susceptible, every unprejudiced person will look with satisfaction at what has already been accomplished, and as the existence of this force is fully established, the hope may reasonably be cherished that further investigation will enable us to apply it more extensively. Whether this new motive power will ever replace steam, as many have confidently asserted, we are not yet in a condition to say positively: before that can happen we must be enabled to generate electro-magnetic force of any degree of strength that we please, as we can steam; it must possess the power of imparting to machinery every required velocity; it must be capable of being regulated as steam power is, at the pleasure of man; and could even all these requisites be complied with, and though it possessed the advantage of involving no risk of life in its controul, there would remain one important element to be considered, viz., whether its economical effect, *i. e.* its useful effect, when compared with the cost of generating and working it, exceeds that of steam. The main point would therefore be, that we should find materials for generating this force as abundantly supplied as those by which steam is created: for with the present construction of electro-magnetic machines, and with the materials now used for producing the force, it is out of the question to think that it can be substituted for a fraction of the many millions of horse power represented by existing steam engines (§ 420.). Whilst penning these lines, the recollection involuntarily forces itself upon my mind of the illusory anticipations, formed but a few years ago, that steam power was to supersede gunpowder (§ 420.).

II. MAGNETO-ELECTRICITY,

OR THE INDUCTIVE INFLUENCE OF ELECTRIC CURRENTS.

A. *Electric Currents excited by means of others.*

§ 571.

After the electro-magnetic discoveries had established the fact that electricity, in a state of motion, possessed magnetic properties and exerted a magnetizing influence, the natural conclusion was speedily drawn that, conversely, magnetism would call forth electrical phenomena.

Now, as according to Ampère's theory of the nature of magnetism (§ 497.), magnets are assumed to be bodies about which electric currents circulate, the next thing to prove was, what influence such currents would exert on other bodies in a state of electrical equilibrium. The investigations on these points led to the following results:—

1.) *Electric currents act precisely as electricity in a state of tension would act on conductors within the sphere of their influence, that is, they by induction excite currents again in these bodies.* The electric currents thus generated are called *induced* or *secondary currents*, whilst those which existed originally are termed the *inducing* or *primary* currents.

2.) *A secondary current will be elicited in a closed metallic conductor, when brought near to or when removed from a current already existing, also when an electric current is called into existence or is suspended in its neighbourhood.*

3.) *These secondary currents are only of momentary duration, whereas the primary are permanent.*

4.) *The secondary current which is first generated,* viz. *that which is formed by bringing the unelectrified conductor near to the* *primary current has the* opposite *direction to it, whereas t final one, which is formed by the removal or suspension o mary current, has the same direction with it.* Hence i that the secondary currents always have the contrary dir that which a current in the unelectrified conductor m had to cause their approach or recession.

Further research showed that a secondary current been elicited by a simple or rectilinear primary one, had but a small intensity, became much more powerful conductor of the primitive and that of the secondary were coiled under each other in a spiral form, becaus means the single force was multiplied in the same man a galvanometer, §§ 512. and 547.

The brief duration and the small intensity of excited by induction, caused them to be so long ov by many distinguished men of science. Faraday first who, towards the close of the year 1831, disco laws by which the inductive influence of electric c governed; their existence he proved by increasi effect through using a great many coils of wire.

This distinguished philosopher endeavoured to for the brief duration of these currents agreeably to of the induction of electricity in a state of tens (§§ 478. and 483.). At the moment when electri librium is disturbed by a primary current in a el ductor, it will attract one electricity and repel t Thence two currents arise, one running in the direction to the primary current, the other in t direction with it. Now the latter, by the laws o currents (§ 549.), will be attracted by the primary its action will be thereby suspended whilst the o move on with great velocity. The induced c during the continuance of the current which acts in a peculiar latent state, called by Faraday the *el* state, resembling a conductor put in a state of te induction. When this condition terminates, the that had been held back so long as it lasted is set and moves in the direction of the exciting current.

The following experiments will display the cr these secondary currents, their brief duration, and regulating their direction.

First Expt. Two fine copper wires covered will serve as conductors of the primitive and s currents. Coil both under and over each other wooden cylinder in which there is a deep groov the entire number of turns may amount to several *Fig. 248.* represents one of these induction spirals;

Fig. 248.

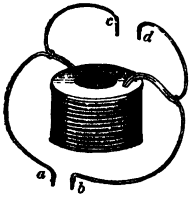
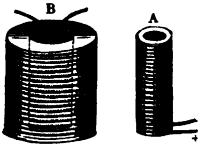


Fig. 249.



are the ends of one, *c* and *d* those of the other wire; and that the ends of the respective wires may be readily distinguished, it is advisable to cover them with silk of different colours. Connect the ends of one wire, *ex. gr. a* and *b* with the poles of a powerful constant battery, then the current in this conductor will circulate close to the other conductor without being able to pass over into it. The second wire will accordingly serve as the conductor of the secondary current, and that the effects of induction in it may be readily seen, connect its ends *c* and *d* with a galvanometer. At the moment when the battery is connected by means of the first wire, the deflection of the galvanometer needle shows a secondary current to have been elicited in the under wire. If the primitive current in the first wire go from *a* to *b*, the needle would show that the secondary current had gone from *d* to *c*. After a few oscillations the needle reverts to its original position, thus proving that the induced current had ceased to exist. Interrupt the primitive current by breaking the connection of the battery, and the needle will instantly turn in the contrary direction; showing the existence of a current in the under wire flowing from *c* to *d*, in the direction therefore of the principal current whose action had been suspended.

Second Expt. To show how secondary currents are produced by bringing one conductor near to another and by withdrawing it, the latter being traversed by electricity, it will be necessary to use two separate induction spirals. The inducing spiral whose ends are connected with the constant battery, consists of a wooden roller on which are several hundred coils of copper wire about one line thick, as shown in *fig.* 249. A; the wire is covered with silk. The other in which the secondary current is to be generated consists of a similar wooden roller, *fig.* 249. B, hollow in the middle and large enough to slip over the other. It contains some 1000 or more coils of fine copper wire coated over with silk; its ends are connected with a galvanometer. The phenomena described in the preceding experiment occur when the second spiral is thrust over the other, and when it is detached from it.

§ 572.

Soon after the discovery of these secondary currents it was found, as was to be anticipated, that they produced not merely magnetic, but also physiological and luminous phenomena, like other electrical currents; on account of their alternate action they exert no chemical influence. To render their physiological effect on the human frame perceptible, there must be a rapid succession of breaks in the primary current; this may be effected by inserting a contact breaker in the circuit.

When a frog's leg was connected with the ends of the induced spiral, contractions took place on each opening and closing of the battery. Sparks also accompanied each of these changes when the amalgamated ends of the wires were brought together.

To magnetize a steel needle, place it in a spiral wire just as when a permanent hydro-electric current is used, the ends of this spiral being connected with those of the induced spiral. Only one of the secondary currents should be allowed to pass through this conductor, or else the magnetic influence exerted by the one current will be annihilated, or at least impaired by the other which flows in a contrary direction.

A shock may be received from a current proceeding from one element of a constant battery, if the metallic ends of the spiral in which the secondary current is generated are grasped with wet hands, and the effect will be heightened if the ends of the wires are furnished with such conductors as we have described in expt. 6. § 515., and the person who is to receive the shock holds these instead of the mere wires. With the common voltaic current a pile of at least thirty pairs of plates is required to produce a shock; the current of the single battery is in this case rendered more powerful by being transmitted through repeated coils of the wire.

§ 573.

Every electric current, on the connexion with the battery *being broken* and renewed, excites a special current in its own

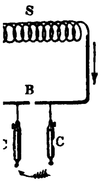
Faraday attributes this to an inductive influence coils of the same spiral exert on each other: the cur- produced he calls the *extra-current*. The extra-current on connecting the battery, like the secondary current, ontrary direction to the primary, the predominance of therefore neutralizes it; that which ensues on breaking xion has the same direction as the primary current, arkable for the effects it produces, being distinguished by the intensely bright sparks and the powerful shocks f.

rst Expt. Connect the mercury cups at the poles of a le but strong voltaic battery (best of all of platinum or n), by means of a short copper wire; on breaking and ving the connexion a very feeble spark will be obtained, f the poles are connected by the long wire of an induc- spiral each time the ends are inserted in the mercury and are removed from them, a vivid spark and an le report will be observable.

ond Expt. Connect the poles of the battery with the llic conductors which are to be grasped in the hands, he nerves will be affected each time the connexion is lished and broken; but the intensity of the shock will creased within certain limits in proportion to the er of turns in the helix of an induction spiral inserted en one pole and one conductor.

th the luminous phenomena and the electric shocks endered more forcible by interposing any contact- er; the sparks are remarkably brilliant if a Ritchie's ry electro-magnet (*fig.* 247.) is employed. To obtain pid succession of shocks the contact-breaker must be inserted in that part of the conductor which is between the conductors that are held in the hands. *Fig.* 250. will render this arrangement more intelligible; E is the battery, S the spiral connected with one of its poles, B is the contact-breaker, and C C are the conductors. At each interruption the extra-current runs from the conductor through the human body.

Fig. 250.



When the current is interrupted and renewed with sufficient rapidity and con- nce, the extra-current, as Faraday has proved, exerts al, chemical, and magnetic influences.

§ 574.

Even the momentary current of frictional electricity, obtained by discharging a Leyden jar or an electrical battery, excites, in closed conductors standing near the conductor of the momentary current, induced or secondary currents, whose properties have been investigated by P. Riess and Dove in a comprehensive series of ingenious experiments. An instantaneous primary current of this kind generates only one secondary current, which has always the same direction with itself, and which produces effects thermal, magnetic, and physiological, strictly analogous to those caused by permanent electric (voltaic) currents. Want of space forbids our entering more into detail as to the properties of these currents.

B. *Electric Currents generated by Magnets.*

§ 575.

It was to be expected from the discoveries made as to the inductive influence of electric currents, that if Ampère's hypothesis were correct, magnets would produce effects strictly analogous to those displayed by an induction spiral, through which there flowed a stream of voltaic electricity. The experiments performed to establish this point have fully proved it. *A magnet by induction excites in an unelectrified closed conductor a current both on being brought near to, and on being removed from the latter. While the magnet is at rest, and near to the conductor, no current is perceptible in the latter.* These secondary currents have the same directions as they would have received from a magnet (§ 557.), according to the fundamental law of the induction of electric currents (§ 571.), based on Ampère's hypothesis.

Our first knowledge of the existence of these *magneto-electric currents*, as they have been called, is due to Faraday, who discovered them towards the close of 1831, simultaneously with the secondary currents that are generated by voltaic currents.

The following may be regarded as the fundamental experiment:—

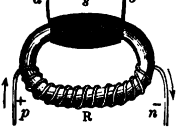
Expt. Insert one leg of a powerful horse-shoe magnet in the hollow cylinder of an induction spiral, *fig.* 249 B, whose ends are connected with a galvanometer, and the deflexion of the needle will show that a secondary current has been generated in the spiral whose direction is contrary to that of the currents circulating about the magnet. — If the leg of the magnet remain at rest in the cylinder, the galvanometer needle will, after a few oscillations, resume its normal position; the copper spiral is consequently in an *electrotonic* state (§ 571.). — Withdraw the magnet after the needle has become steady, and it will again deviate, but in a contrary direction to that in which it moved when the magnet was inserted in the spiral. — Insert the other pole of the magnet in the cylinder and the direction of the needle's deflexions will be reversed. — In these experiments the wires from the helix must be long enough to prevent the magnet's acting on the galvanometer needle.

§ 576.

oft iron, which has been rendered temporarily magnetic by permanent electric current of a voltaic or of a thermo battery, y induction from a steel magnet, excites secondary currents n induction spiral in precisely the same manner as a magnet ld. The first case may be verified by surrounding an electronet in an induction spiral, then establish and break the conion of the battery from which the current proceeds to its x, and it will be alternately in a magnetic and in an unmagc state. In the other case the same effect follows if a piece ft iron, placed in the induction spiral, be alternately magnetand demagnetized by approaching and withdrawing a powerteel magnet.

First Expt. The Magneto-electric Ring, fig. 251., is one of the most simple pieces of apparatus for generating magneto-electric currents by means of an electro-magnet. It consists of a bar of iron about 1 inch thick, bent round, so as to form an oval ring, whose longer inner diameter may be somewhat about 3 or 4 inches. One half R is converted into an electro-magnet, by having some insulated copper wire of sufficient thickness twisted round it, the ends of the wire being connected with the poles of a constant battery; the other half, which answers to the feeder of an electro-magnet, is surrounded with the inductive spiral *s*. Connect its extremities *a* and *b* with a galvanometer, and its needle will

Fig. 251.



there, on the connexion of the battery being broken a renewed, the same effects as if its place had been supp by an electro-magnet.—A common electro-magnet mi have been used in performing this experiment, if its fi by which the poles were connected, were inserted in t induction spiral.

Second Expt. To show that these currents may be ge and by the inductive influence of a steel magnet, brin [illegible], such as we have just described, near to the po a powerful horse-shoe magnet, and then withdraw it. bringing the pole of the magnet near the two ends of [illegible], the galvanometer needle, which is connected wi spiral, will show the existence of a current, whose dire is opposite to that of the current which, by Ampère's th is supposed to encircle the soft iron that has been conve into a magnet. On withdrawing the magnet, the cont deviation of the needle proves that the second secon current has been generated, and that its direction i same as that of the current which had just been suspe in the iron.

§ 577.

Lenz has investigated and discovered the laws which re the magneto-electric force excited by magnetism in the indi spirals. The results obtained by this philosopher co exactly with the laws which he and Jacobi had previously to regulate the intensity of the electro-dynamic force excit voltaic currents (compare § 568.). These laws are,

1.) That the magneto-electric energy excited in an ind spiral by means of magnetism, is equal to the sum of the el motive forces of all the individual coils of the wire (Ohm damental law, § 511.).

2.) "Cæteris paribus," that is to say, with equally po currents, the magneto-electric force will be nearly propo to the number of coils, the thickness of the wire exerti influence on it: its intensity will, however, be slightly dimi by increasing the width of the coils.

§ 578.

The action of a hydro-electric induction spiral may *combined with* that of an electro-magnetic spiral: place n within the hollow cylinder of a spiral through which ary current flows, and the secondary current generated mbined influence of the two forces will be more power- if excited by either of them singly. The soft iron magnetic every time that the contact of the voltaic established; it loses its magnetic properties again when broken; it acts therefore in both cases inductively, like ic current on the outer coils of wire. In this kind of apparatus the extra current which is generated at the when contact is broken, possesses remarkable energy in ff sparks and shocks; subsequent observation has shown e effects are rendered still more powerful if a bundle of s be used instead of a solid cylinder (a).

ese principles have been constructed *galvano-magnetic machines*, which have been variously applied, but whose use is for medical purposes; they consist of an induc- l connected with a hydro-electric battery, which is fitted an apparatus for establishing and breaking contact with idity.

) Bachhoffner and Sturgeon appear to have first ced that a bundle of wires, insulated by a coating of ish, gave a more powerful extra current than a massive of iron. Magnus and Dove tried to ascertain the cause his increased effect; they found that when the wires inclosed in a metal case, the force of the current was same as if it had been sent through a solid iron. But n the tube was slit, or when the wires were not inclosed ll, the efficiency of the current was greatly heightened. e found, on prosecuting his inquiries still farther, that perfectly equal induction spirals, provided with different or sets of wires, even if they deflected the needle of a anometer equally, gave shocks of unequal intensities; herefore inferred that the increased physiological effects nd partly on the internal structure of the iron, partly he discontinuity of its mass, and that the greater effect wing to the more rapid suspension of the current caused this discontinuity; the greater intensity of the shock, ed by rapidly establishing and breaking the contact of battery, admits of a similar explanation.

) One of the simplest and most ingenious contact- kers for machines of this kind, has been invented by M. gner, of Frankfort-on-the-Maine: it possesses the advan- of simplicity of construction, and also that of having notion maintained by the electro-magnetism elicited, in respect resembling Ritchie's rotating electro-magnet. 252. will show its construction; the mechanical com- tion will, however, admit of various modifications.

show, on the connexion of the battery bei renewed, the same effects as if its place ha by an electro-magnet. — A common electr have been used in performing this experim by which the poles were connected, wer induction spiral.

Second Expt. To show that these curre ated by the inductive influence of a steel feeder, such as we have just described, ne a powerful horse-shoe magnet, and then bringing the pole of the magnet near th feeder, the galvanometer needle, which is spiral, will show the existence of a curr is opposite to that of the current which, b is supposed to encircle the soft iron that into a magnet. On withdrawing the m deviation of the needle proves that th current has been generated, and that it same as that of the current which had in the iron.

§ 577.

Lenz has investigated and discovered the the magneto-electric force excited by magnet spirals. The results obtained by this exactly with the laws which he and Jacobi to regulate the intensity of the electro-dyna voltaic currents (compare § 568.). These la

1.) That the magneto-electric energy ex spiral by means of magnetism, is equal to the motive forces of all the individual coils of th damental law, § 511.).

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§ 578.

The action of a hydro-electric indu *combined* with that of an electro-magnet

may be produced by
a voltaic pile consist-
It is therefore used
ical effects by alter-
arcoal points to a state
; the current, however,
and with its direction

fig. 253 *b.* a perspective
e. N J S is a powerful
rizontal position. *s* and
feeder, whose axis *a b* is
W by an endless strap,
ed wheel *r*: this sets it in
s turn round close to the
b of the axis acts as a com-
s, one of which *m* has a me-
. while the other *p* is insu-
slipped over it. The free
nected with the feeder at *c*;
site side, with the insulated
way the two metallic capsules
helices from which the cur-
f the current from these parts
gs, one of which *f* lies above
the metallic caps, and which,
per stems, are connected with
which thus, in a manner, con-
entire machine. If now we
the helices represented in *fig.*
M the negative pole, after one
would become the negative and
tion of the current would con-
so soon as this change took
pirals, the electrical condition of
of the commutator would be
same time when this happened
which the current is conducted
nto contact with these oppositely
urrent becomes again changed;
hat if P and M are connected the
as to its direction from P to N.
electric sparks a rapid succession
. The break must occur on the
ximum intensity, which happens
are midway between the two
tically one above the other, as i

fig. 253 *b.* To effect this there are depressions or holes *o*, *fig.* 253 *a.* in the middle of the two halves *p* and *m* of the commutator; *i. e.* about 90° from the places where the *change occurs* in the current. The forked spring *f* is then

Fig. 253 *a.*

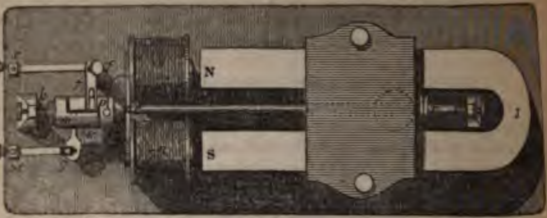
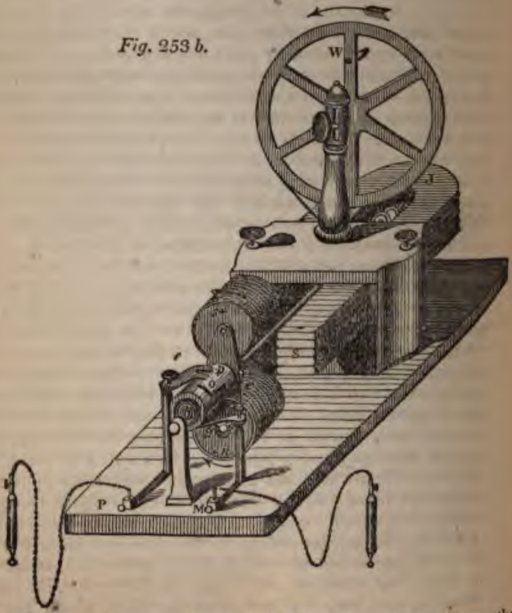


Fig. 253 *b.*



so placed that one half lies on the part *p* of the capsule when it moves on without any break, whilst the other is bent so that it falls into the depression *o* as the inductor turns round, and thus breaks the conduction and the current; in like manner, the second spring *g* is bent so as to come on the unbroken part of the commutator *m*. This position of the springs is shown in *fig.* 253 *c.*

Fig. 253 *c.*

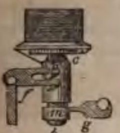
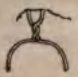


Fig. 253 *d.*



To obtain the physiological effects, and especially the magneto-electric shocks, in rapid succession, connect the metallic conductors (§ 515.) with the binding screws P and M; grasp one in each hand, and set the machine in action. Two shocks will be felt at each revolution, and if the inductor be whirled round rapidly the muscular contraction will become too violent to be borne. The same arrangement of the springs will serve to show luminous phenomena as generated by magnetic induction. They will be visible at the breaks in the conductor at the instant when the spring *f* falls into one of the holes *o*. A vivid white electric light will appear in the groove, and if a steel spring be presented to it, it will immediately be surrounded with reddish sparks. As we have already remarked, these phenomena will be most brilliant if a quantity inductor is used, in which case the sparks will frequently have a length of several inches. The chemical effects, for producing which the intensity inductor will be the best adapted, may be obtained by using a constant direction of the current (which may be ensured by placing the springs *f* and *g* in the position *fig.* 253 *a.*), and connecting the electrodes of a decomposing apparatus with the two binding screws P and M. The decomposition of water, as also of an alkaline or heavy metallic salt, may be effected in the same manner as by a hydro-electric current. Woolrich in England and Stöhrer of Leipzig have successfully applied these currents to electro-gilding and silvering (vide § 519.). The splendid light of the charcoal points is obtained by using two of these points to establish contact (§ 514.), having previously connected them with the poles of the machine. To render platinum wire incandescent the quantity inductor should be used as shown in *fig.* 253 *a.*: secure a short, thin piece of platinum wire between two copper wires covered with silk and twisted into a fork, their other ends being fastened in the binding-screws P M. In like manner thin iron and steel wire may be burnt; or twist the wire you intend to burn about a wire of pure metallic copper connected with one pole of the machine, and touch the other pole with the short free end of the iron wire. Lastly, to produce its magnetic effects, such as the deflection of the needle, the excitation of temporary magnetism in metals and electro-magnets, and the various electro-magnetic rotations, convey the constant current of the quantity inductor from the two poles of the machine through the electro-magnetic apparatus used in the particular experiment.

An electro-magnet may be substituted for a steel one in these machines, and then the rotation of the inductor will be effected by the changes of the current in the electro-magnet. This variation was first introduced by Pohl.

§ 580.

The discoverer of magneto-electricity could not fail, from working out the laws of magneto-electric induction, to hazard a conjecture that the earth itself must necessarily act in this respect also like an electro-magnet. At first he succeeded only indirectly in obtaining such an effect from terrestrial magnetism by thrusting an induction helix over a bar of soft iron, the ends of the helix being connected with a delicate galvanometer, and then placing the bar in the same position as the dipping-needle. By the inductive influence of terrestrial magnetism the iron bar acquired a north pole at its lower extremity (vide § § 446. and 457.), and thereby induced a current in the helix, which, as the deflection of the galvanometer showed, was the same as we should have had by inserting the north pole of a bar magnet within the helix (§ 575.). The same effect followed when the helix was put in the position of the dipping-needle, and the cylinder of soft iron was thrust into it. On withdrawing the cylinder the needle was deflected in the contrary direction, precisely as if the north pole of a bar magnet had been withdrawn from the helix. Faraday subsequently succeeded in producing induced circulating currents, in various ways, by the influence of terrestrial magnetism. Copper wire, for instance, was coiled round a rectangular wooden frame, each of whose sides was about two feet long, and the ends of the wire were connected with a delicate galvanometer; the frame was then set in rapid motion, with its plane in the magnetic meridian. It was turned from W. to E., and the deflexion of the needle showed that an electric current was produced answering to the terrestrial current, which, from Ampère's hypothesis, is supposed to flow from E. to W. On withdrawing the conductor from this position, or on reversing the movement, the needle was deflected in the contrary direction. These effects

: extremely feeble of themselves, may, by a number of
ts answering to the vibrations of the needle, be so in-
ı force as to deflect it 180° from its normal position.

§ 581.

electric currents excited by magnetic induction depend
enomena which conducting bodies display when magnets
d over them, or inversely when the conducting bodies
s are in motion and their movements are affected by
ı of magnets. These phenomena may be divided into
s, viz. such as attend the vibrations of magnetic needles
of proximity to non-magnetizable bodies, and such as
een a magnet and one of these bodies, when one or
ıade to rotate near to the other. The general name of
Magnetism has been given to all this class of phe-

§ 582.

; these phenomena must be reckoned the diminution
by the oscillations of a magnet performed above a plate
The isochronism of the oscillations continues unim-
ıt the arcs moved through by a declination and by a
eedle, as also those of a magnet swinging as a pen-
e less if performed in the proximity of a mass of metal
would otherwise be. The influence exerted by the
ries in degree, that of copper and silver being greatest,
f mercury the least; in all cases the effect is increased
tal is brought near to the oscillating magnet.
ıe phenomena (see § 463.) observed by Coulomb in
, and by Hansteen, were owing to these influences.
o investigated the subject more closely in 1824, in
r to discover what influence the different metals exer-
on magnetic needles vibrating near them. Seebeck
ed his researches still further, and arrived at the follow-
mportant results. He first found the relative retarding
of the different metals on a magnet. A declination
le which performed 216 oscillations in the common air
ducing its arc from 45° to 10°, had its excursions
ced equally when the following metals were presented
at a distance of 3 lines, viz.

Over Mercury after 112 oscillations,
— Bismuth — 106 —
— Platinum — 94 —

Over Antimony	after	90	oscillations.
— Lead	—	89	—
— Gold	—	89	—
— Zinc	—	71	—
— Tin	—	68	—
— Brass	—	62	—
— Copper	—	62	—
— Silver	—	55	—
— Iron	—	6	—

He found further that the retarding effect increased as the number of plates, or the thickness of the single plate, if one only were used, was increased; this must be considered as holding good only within certain limits, no corresponding influence attended an increase of the surface; the effect of all the metals diminished exactly as the distance increased; the number of oscillations underwent no change if glass, wood, or paper, were interposed between the metal and the needle; heating the metal plate produced no modification of its influence; any disturbance in the connexion of the different parts of the plates diminished their influence on the magnet; and lastly, heavy needles were more easily affected than light ones.

Arago found in 1825 that even non-metallic substances, as water, ice, glass, &c., exerted a disturbing influence on the oscillations of needles, but in a much lower degree than the metals.

§ 88.

Immediately connected with the phenomena we have just described are those which arise when a magnet at rest is suspended over a metal plate in a state of rapid motion, or when a horseshoe magnet revolves with its poles uppermost beneath a plate suspended horizontally above it. These are properly the *phenomena of magnetic rotation*; they were first noticed by Arago in 1825, and have since been repeatedly observed by other philosophers.

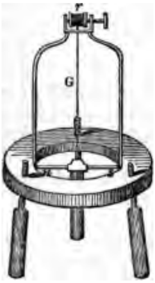
They are as follow:—

A declination needle suspended a little above a plate of metal is deflected from its polar position on a rapid rotation being imparted to the latter about its centre; its deflexion will be in the same direction as that in which the plate turns; it increases as the rotation becomes more rapid, and on its amounting to 90° the needle revolves with the plate.

Babbage and Herschel performed the converse of this experiment of Arago's, by making the magnet to revolve under a al plate suspended freely above it, and found the movement he plate in this case to correspond with that of the needle in former.

First Expt. These experiments will be most easily performed by using the whirling table (*fig.* 7. vol. i.), on the revolving axis of which fasten a copper plate two or three lines in thickness, and cause it to revolve with sufficient rapidity. Over the copper plate or disc place a table, *fig.* 254., in which a circular hole is cut of the same size as the disc; close the opening with a pane of glass, and bring the revolving metal as near as possible to it. Now set a bell glass on the pane of glass; the former must contain a pretty strongly magnetized steel bar *n s*, suspended by a silk thread; this magnet should be made to rise or fall at pleasure by means of a roller *r*. The intensity of the action which the revolving disc of metal exerts on the bar magnet, the velocities being equal, is greatest when the magnet is nearest to the glass plate, and it decreases in proportion as its distance is increased by winding up the roller.

Fig. 254.



Dr. Böttger advises that instead of a common bipolar magnet we should use one whose two ends are equal and similar poles. Magnets of this kind are almost indifferent to the influence of terrestrial magnetism, and are equally as strongly magnetic, which last circumstance is of considerable importance to ensure the successful performance of these experiments in rotating magnetism. One of these tripolar magnets will instantly follow the copper plate, even if the latter revolve with but a moderate velocity. We have already stated in § 454. and § 567. how these astatic needles may be easily made; it is worthy of remark that those made in the latter of these ways by means of the electric current are generally more powerful and more completely neutralized.

Second Expt. Instead of the copper disc, now place a powerful horse-shoe magnet on the axis of the whirling table with its arms upwards, and suspend a copper disc in the bell glass instead of the magnet, as in the first experiment: on causing the horse-shoe to revolve, the copper plate will turn round also.

In both these experiments the intensity of the action will be affected by substituting plates of some other metal instead of copper. Babbage and Herschel have in a twofold manner [illegible] When made [illegible] current which [illegible] upper edge, when [illegible] edge to the centre.

[illegible] magnetic in- [illegible] from fig. [illegible] N represent [illegible] the arrows [illegible] according to Ampère's hypothesis, it is clear that these currents [illegible] contiguous [illegible] which in the [illegible]. Now let the disc [illegible] same direction [illegible] arrows a b, and the galvanometer will indicate a current proceeding from the centre of the disc towards the edge; and if the rotation were reversed the needle's deflection would show that the current went from the edge to the centre.

Fig. 255.

Now break the connexion of the disc with the galvanometer, and the induced currents will necessarily complete their course within the disc itself, for they cannot be carried off by the wires after contact has been broken; from these currents, then, those various influences on the poles of the magnet are derived, which generated the inductive action.

Second Stage. After Faraday had, by means of the first experiments, established the production of induced currents under the operation of the above-named influence, he took a rectilinear slip of copper *a b fig.* 256, amalgamated its edges, on which he laid the copper cylinder *c d*, likewise amalgamated, which was connected with the galvanometer *g*, and so formed the circuit *e g d*: on this strip of copper he placed the north pole *n* of a powerful magnet, and moved the strip under it, as from *a* towards *b*. This pole then excited in the conductor a current running, as the galvanometer showed, from *n* over *d* to *g* and *e*, a course strictly agreeable to the laws of induction. Observe the currents existing in this pole according to Ampère's theory, as they are represented by the arrows in the *fig.*, and in each constituent part of the strip *a b*, which approaches the pole, *ex. gr.*, in *e f* a current will be generated from *e* to *f*, because the part *e s* of the current will act more powerfully than the part *w n*. Now if this portion com

Fig. 256.

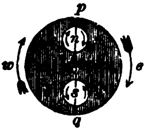
under the pole, that is, if it be situated like *e d*, it will recede from the current *e s* and will be brought nearer to *n w*; both will therefore act inductively in the same direction and hereby produce a more powerful current in the direction from *c* to *d*. Again, if *e f* move farther, *i. e.* come into the position of *h k*, it will be farther from the current *w e*, and consequently the current must now flow again from *h* to *k*. If in this experiment the strip of copper be moved in the contrary direction, or if the north pole be substituted for the south, the currents will flow in the opposite direction to that given in the *fig.*

Agreeably to this experiment, and in accordance with the law f magneto-electric induction, a bar magnet standing vertically bove a rotating metal disc and in its centre, cannot excite any urrent in the latter, because in such a position of the magnet rith regard to the disc, the latter can neither approach towards ior recede from the former. But so soon as the pole of the nagnet is moved beyond the centre of the disc it will induce a urrent in the latter, which will flow in an opposite direction to he current Ampère supposes to exist in the magnet at those parts f the disc which *approach* the pole, and in the same direction rith this hypothetical current in those parts which *recede* from the ole. Hence between the magnet and the parts of the disc which pproach it repulsion predominates, whilst between it and the arts which recede attraction prevails, and on the resultant of hese two forces the tangential, the perpendicular, and the radial ction of the disc depend.

If there be but one pole above the disc of metal, as happens vhen a bar magnet stands vertically over it, then the latter is ffected by the two opposite systems of currents in such a manner hat it is repelled by those which approach and it is attracted by hose which recede from it; the repulsion consequently predominates over the attraction, and accordingly the pole recedes from he disc.

Fig. 257. will render this more intelligible. Let the larger circle represent the disc of copper revolving in the direction of the arrows, *w* and *e*; let *n* be the north pole of a magnet, then the part *a b* of the disc corresponds with the strip of copper in Faraday's second experiment, and the current generated under the pole in the disc by the first experiment will go from the centre to the circumference, *i. e.* from *m* to *p*. But if the south pole, *s*, stand above the plate and *a′b′* is the direction in which it revolves beneath it, then the induced current *q m* proceeds from

Fig. 257.



APPENDIX.

Vol. II. Page 143.

Professor Moser of Königsberg entertains a somewhat different opinion, as to the origin of the photographic pictures, from that expressed in the text. Since the publication of the experiments which led him to form this opinion, they have been repeated with variations by Knorr, Hunt, Karsten, Waidele, and others. The result was that Moser's observations were confirmed, but additional effects were noticed that could not be fully reconciled with the theory this professor had advanced. It may not be amiss to give a brief sketch of Moser's discoveries, and of the important inferences he deduced from them; we shall then mention the theories which have been formed by the other philosophers just named.

Moser ascertained, from a great variety of photographic experiments, that Light was not the only agent that imparted to certain substances the property of condensing the vapours of mercury and iodine on those parts of their surface which were subjected to its influence, so as to depict upon them a representation of the object from which the light was emitted; but that the same effects were produced in the absence of any perceptible light; that images were obtained not merely when silver plates were used that had been prepared in Daguerre's method, but on many other substances; that other vaporisable bodies besides mercury and iodine, were equally efficacious in acting on duly prepared surfaces.

The following are the principal experiments performed by him:—

A coin was laid on a clean well-polished glass plate, the latter was breathed on and the coin was removed; on breathing again on the glass the outline of the coin became visible. Breathe uniformly on a clean pane of glass, and write on it with blotting paper, pencil, or indeed with almost any material; allow the glass to dry, and each time that it is breathed on afterwards, the writing will become visible; this experiment may be repeated for a considerable time.

Other polished substances will do equally well with glass, as Moser found by using plates of metal, stones, resin, wood, leather, &c.; it is by no means indispensable, that the surface should be polished, as the phenomenon obtained when ground glass was used.

The surfaces of liquids are also adapted for these experiments.—Hold any body over some quicksilver in a state of repose, and breathe on the other portions of the fluid, or, it will be better still, if you breathe on the mercury first, and remove the moisture lightly, by any means whatever from certain parts of the surface, and if the metal be not disturbed, the traces will be distinctly seen for days whenever the mercury is breathed on.

Immediate contact is not essential, in order to produce these appearances, either prior to breathing on the surface, or in order to remove the moisture from particular points of it. Hold a screen in which some apertures have been made, over any polished body, so that it may not touch the latter, breathe on it, and allow the moisture which is condensed to evaporate; the figure of the apertures will be renewed at every subsequent breathing.

The vapour of mercury acts in the same manner as that of water, but more powerfully. Expose a polished silver plate to this vapour without breathing on it, and a beautifully distinct image will be formed of the objects previously in actual or in proximate contact with the plate.

Moser tested in like manner the vapour of iodine, which is peculiarly interesting, because it combines chemically with the silver, whereas the mercurial vapour is merely condensed without effecting any chemical change in the substance of the silver. When a prepared silver plate was exposed to the action of the vapour of iodine, in some cases, an image of the objects that had previously been in contact with it, was indicated by a difference in the colours, but whenever the plate was exposed (as in taking the Daguerreotype pictures) to mercurial vapour, a perfectly distinct image was invariably obtained, the daylight bringing out the delineation of the objects with the utmost exactness.

From a consideration of these facts, Moser drew the following important conclusion, that *if the surface of a body be brought in contact at certain points with any other body whatever, it acquires the property of condensing all such vapours as adhere to it or with which it combines chemically, in a different manner at the points of contact, from that in which it condenses them at the other parts of its surface.* Hence then we obtain the picture of the touching body.

The most important point in these phenomena, as far at least as regards the inferences deduced from it, is this, that these pictures may be produced by contact and condensation, when all light is completely excluded. Hence he goes on to say, that *the contact of bodies, the condensation of vapour and the action of light bring about similar changes in bodies, and that those changes which are produced by the first two modes,* ARE MERELY THE EFFECT OF LIGHT WHICH IS TOO FEEBLE TO BE APPRECIABLE BY OUR ORGANS OF SIGHT. Moser's idea is that *all bodies are to be considered as self-luminous*; the light which emanates from dark bodies, he distinguishes as *invisible light.* He thus proceeds: If vapours act in the same manner as light, then although there may be no visible development of light, we must attribute the effects produced by the condensation of vapours to an unseen influence of light. *which when held in this state in the vapour may properly be spoken of as latent light, it is liberated at the moment when the vapours are condensed, and exerts an influence and produces effects resembling those of light in its ordinary condition.*

Professor Knorr of Kasan repeated Möser's experiment of obtaining facsimiles of two bodies, by placing them one on the other; and directed his attention chiefly to the remark made by the latter, that these pictures were both more distinct, and were obtained in a shorter time, when the two bodies were at different temperatures. His experiments proved, that on attaining a certain difference of temperature, which, however, varied for different bodies, *pictures might be obtained even when the vapours were not condensed.* These pictures became instantaneously visible; and, according to the methods used to produce them, they were either transient or permanent. To distinguish them from the images noticed by Moser, Knorr called them *Thermographs.* He believed that they owe their origin, not merely to the difference in the temperatures of the two bodies, but also to the heights of these temperatures; and as they are produced even when the temperatures of the bodies are both equal and constant, he regarded Professor Moser's theory of invisible light as an unnecessary assumption, considering rather that this phenomenon may serve as a demonstration of the truth of Prevost's theory of exchanges.—(§ 885. p. 172. Vol. II.)

Mr. Hunt of Falmouth, who performed the like experiments, is also of opinion that these pictures are the effect of a purely thermal influence.

Professor Karsten has published another mode by which pictures of this kind may be produced. It consists in placing two bodies in contact, and sending electrical discharges through them; breathe on them, and as the vapour is condensed the image is rendered visible. Karsten calls them *electrical pictures.* This phenomenon had, however, been previously noticed by Professor *Riess.* Karsten by no means admits the hypothesis of the *existence of invisible* light; alleging, what indeed Moser admits, that it is not to be attributed to solar light, but is to be considered as inherent to all bodies: then says he, Probably it is not light at all, but rather the exertion of a force possessed by all bodies. He attributes all these phenomena to *molecular changes; and as light, heat, and electricity are all equally efficacious in producing them, their cause is rather to be sought in the influence of cohesion than in light.*

Dr. Waidele of Vienna has also thoroughly tested the experiments and observations of Professor Moser; and on comparing his own with them he thinks he is warranted in saying, that *all the effects of invisible light may be explained by referring them to the unequal capacities of bodies for absorbing gases.*

He found that when an object was brought near to a polished disc, the effects produced depended on the circumstances in which the two bodies stood with regard to the gas they absorbed, a mutual action taking place only when they were in a different condition. Either a coating of the absorbed gases was imparted to the plate, or a portion of the gaseous atmosphere adhering to the plate was withdrawn from it by the touching body, or an exchange of the gases each had absorbed was made at their points of contact.

A liquid or a gaseous body brought into proximity with the plate, so as to touch it at certain points, produced similar effects, inasmuch as it induced a change in the gaseous atmosphere about the plate.

These changes are rendered visible by the condensation of the vapours on the plate, whilst the colouring of the condensed vapour varies according to the state of the gaseous atmosphere about the plate.

The brief comparison we have just given of the different views entertained by several distinguished men of science will show, that the important theory propounded by Professor Moser with regard to invisible and latent light has not yet received the universal sanction of the scientific world. The importance of the hypothesis, as being based on new analogies, which had been detected between light and heat, may well lead us to look for further investigation into the subject; and we may sincerely express a hope that the talented professor of Königsberg will produce some further and convincing evidence in favour of the theory he has advanced.

Vol. III., Page 83.

Mr. Grove has also made another voltaic battery, of a novel construction. It belongs to that class in which one hom

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